



Systematic literature review of the relationship between adolescents' screen time, sleep and mental health



HEALTH AND SOCIAL CARE

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Systematic review of the relationship between adolescents' screen time, sleep and mental health and wellbeing

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Funder: Directorate for Mental Health, Scottish Government

Short title: Adolescent screen time, sleep and mental health

Summary

The objective of this systematic review was to summarise the published experimental and longitudinal evidence on adolescent mobile device screen time or use, and the association with sleep and mental health and wellbeing. Five research questions guided this review which included evidence from quantitative and qualitative studies conducted in Western countries classified as high-income by the World Bank.

Key findings

- The body of evidence based on longitudinal or experimental studies is very small: nine quantitative studies and two qualitative studies.
- The quality of individual studies was low and they lacked detailed descriptions of methodology, limiting assessment of risk of bias. This means findings and conclusions should be interpreted with caution.
- The body of evidence is incomplete. There were various types of mobile device screen use (e.g. time spent using a mobile device, social media use) and various outcomes (e.g. sleep duration, sleep quality), and only one or two studies that assessed each exposure/outcome relationship, making it difficult to draw conclusions beyond these individual studies.

1. To what extent does adolescents' mobile device screen time impact on sleep outcomes?

- Mobile phone use around bedtime and cybervictimisation, but not the overall time spent engaging in mobile phone activities per se (at any time of the day), was linked to lower sleep duration.
- Sleep quality was negatively influenced by mobile phone use in general and social media use in particular.
- Experiencing pressure to engage socially using a mobile phone was associated with poor bedtime behaviours that might promote poor sleep quality (i.e. sleep hygiene).
- Stopping phone use one hour before bedtime was not linked to earlier sleep.

- One pilot study (a small scale, preliminary study) showed that use of a smartphone app (under development) that teaches about the importance of consistent sleep and wake times, and recommended bedtimes was associated with a potential improvement in sleep duration, sleep quality and earlier sleep onset.

2. What are the potential causal mechanisms through which mobile device screen time affects sleep outcomes amongst adolescents?

- Experiences of cybervictimisation were indirectly associated with sleeping less than the recommended 8 hours per night. The factor linking cybervictimisation with shorter sleep was repetitively thinking and obsessing about distressing thoughts, emotions, and memories
- Other ***potential*** mechanisms through which mobile device screen time or use affect sleep outcomes are: sleep displacement (i.e. using the phone instead of sleeping), delaying sleep time, increased alertness through blue light exposure, psychological arousal which can result in bodily responses (e.g. faster heart beat) through binge watching and/or watching violent or upsetting content.

3. What are the implications of the potential impact of mobile device screen time on sleep for adolescents' mental health and wellbeing?

- Night-time mobile use and problematic social media use¹ were linked to depressed mood through experiences of poor-quality sleep. Poor sleep quality also played a role in the link between night-time mobile phone use and low self-esteem, poor coping skills and higher externalising behaviour (e.g. disobeying rules, physical aggression).
- One pilot study showed that use of a smartphone app (under development) that teaches healthy sleep habits was associated with potentially lower depressive symptoms and reduced anxiety.

4. To what extent might girls' and boys' differential mobile device screen time, and its relationship with sleep, contribute to inequalities in mental health and wellbeing by gender?

¹ 'Problematic' in the context of the research reviewed referred to agreement with statements that social media use impacted on other social activities, was used as a way to feel good, and caused arguments about the amount of time on social media.

- None of the included quantitative studies reported separate data for boys' and girls' mobile device screen time or use and its relationship with sleep that in turn might contribute to inequalities in mental health and wellbeing for boys and girls.
- In August 2019, a new eligible study was published which we did not include in our evidence synthesis because of its availability after we had completed our literature search.
- The study found that using social media multiple times daily when aged 13-15 predicted lower life satisfaction, lower happiness, and higher anxiety among girls 1- to 2-years later but not among boys.
- It also found that sleeping less than 8 hours per night, not being physically active most days, and experiencing cyberbullying play a detrimental role in the association between social media use and lower wellbeing in girls only.

5. What existing evidence is there on adolescents' views of how mobile device screen time affects their sleep, and following on from this, their mental health and wellbeing?

- In the qualitative studies both adolescent boys and girls reported using smartphones in bed and recognised that it may negatively affect their sleep.
- Adolescents felt that sleep issues were connected to the content in video games rather than their use.
- Boys were more likely to report trying to follow guidelines (e.g. putting electronics away one-hour pre-bedtime) whilst girls suggested they specifically used their mobile screen devices as a tool to aid sleep (e.g. listening to music).
- No study asked young people directly about their view of the relationship between sleep and mental health. However, when young people thought about the importance of sleep they mentioned the 'energising, relaxing, stress-reducing and restorative qualities of sleep'.
- No study asked young people explicitly about the connections between screen use, sleep and mental health and wellbeing.

Recommendations

Policy and practice initiatives could target all or a combination of the identified modifiable factors within the causal pathway between mobile device screen exposures and impaired sleep, but the current evidence severely limits the recommendations that can be made. Only one study provided suitable data to explore potential causal mechanisms through which mobile device exposure influences sleep outcomes. It suggests:

- Young people should be protected from cybervictimisation and mandatory requirements of social media platforms to develop algorithms that block aggressive and upsetting content could be put in place. Education around the impact of cybervictimisation and how to avoid it (e.g. adequate privacy settings) could be embedded in the school curriculum.
- Repetitively thinking and obsessing about distressing thoughts, emotions, and memories as a consequence of cybervictimisation could potentially be targeted by initiatives that strengthen resilience in adolescents, in particular teaching young people and their parents healthy coping strategies (e.g. help seeking and sharing thoughts/emotions, mindfulness).

Further research investigating the causal relationship between mobile device screen use, impaired sleep and mental health and wellbeing is needed. Therefore, future research studies should use multiple time points of mobile device screen use, sleep and mental health data.

Structure of Report

This report will first introduce the literature on the topic of adolescents' screen time, sleep, and mental health and wellbeing. The aims of this review will be introduced along with research questions, methods and results. Results will be broken down by the Research Question first and then by exposure (type of mobile screen time). The report will conclude with a discussion of the findings followed by references and appendices.

Introduction

Poor sleep has been linked to mental health issues such as mood problems, anxiety, and suicidality (1, 2). The recommended amount of sleep for young people is 8-10 hours, however research shows that sleep duration among young people is often much less than this. The number of young people reporting less than 7 hours of sleep per night has increased over the last decade (3, 4). Access to and use of a media device (e.g. a portable device such as smartphone or tablet) at bedtime has been associated with poor sleep quality, inadequate sleep quantity, and daytime sleepiness in young people (5). Studies have also shown that extended periods of screen time can displace positive activities (e.g. outdoor physical activity) that are beneficial for sleep outcomes and mental health (6, 7).

There is also increasing evidence of an association between mobile screen use and adverse mental health and wellbeing outcomes in young people (7, 8). A systematic map of reviews on this topic highlighted the increase in studies exploring the relationship between screen-based activities and mental health outcomes, and in particular, depression (7). Another review published in 2018 found that frequent mobile phone use was associated with depression and problems with sleep in young people (8).

A recent UK survey showed that among 5-19 year olds, 12.8% had at least one mental health disorder and the prevalence increased with age (9). The effects of inadequate and poor-quality sleep in adolescence can be serious and wide-ranging and there is increasing evidence of a bidirectional association between sleep disturbance and depression in young people (10). Poor sleep can lead to depressive symptoms while depression and anxiety are predictors of poor sleep (10) creating a negative feedback loop. The Royal College of Paediatrics and Child Health consulted 104 young people, age 11-24 years, across the UK about their views on screen time use and found that 88% felt that screen time negatively affected their sleep and 35% felt that screen time negatively affected their mood and mental health (11).

Despite the above research, the literature reviews that underpin the most recent advice on screen time and screen-based activities were focused only on television viewing (12). Yet, screen time now includes tablet and mobile phone use. Furthermore, the above systematic and literature reviews were primarily composed of cross-sectional studies (5-8, 10), which cannot answer questions of temporality or causal effects, including the potential mediating role of sleep on screen use and mental health outcomes. There are numerous

calls for longitudinal studies that can clarify relationships between sleep, screen time, and mental health (7, 8, 10) and as these studies are being published with increasing frequency, a systematic literature review on the most recent experimental and longitudinal evidence is needed.

The Scottish Government released a report in 2019 titled: 'Exploring the reported worsening of mental wellbeing among adolescent girls in Scotland' (13). The report highlighted interrelated factors that could be influencing worsening mental wellbeing in Scottish adolescents, including inadequate sleep and social media use.

This systematic review follows on from the existing Scottish Government report, addresses the identified gap in the literature, and adds to the existing evidence reviews as the focus of investigation is the impact of: (i) time spent on mobile devices typically used by young people of the 21st century, and (ii) the type of mobile device activities or uses on sleep outcomes, and how this is affecting young people's mental health.

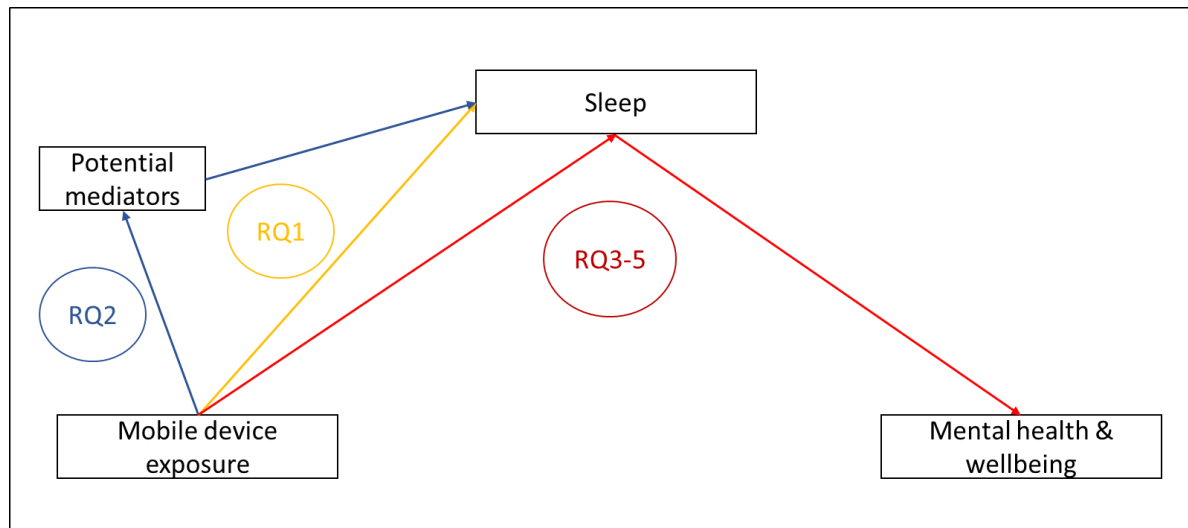
Review aim and Research Questions

The aim of this systematic review is to answer the following Research Questions (RQ):

1. To what extent does adolescents' mobile device screen time impact on sleep outcomes?
2. What are the potential causal mechanisms through which mobile device screen time affects sleep outcomes amongst adolescents?
3. What are the implications of the potential impact of mobile device screen time on sleep for adolescents' mental health and wellbeing?
4. To what extent might girls' and boys' differential mobile device screen time, and its relationship with sleep, contribute to inequalities in mental health and wellbeing by gender?
5. What existing evidence is there on adolescents' views of how mobile device screen time affects their sleep, and following on from this, their mental health and wellbeing?

Figure 1 illustrates the different pathways and directions of associations considered for this systematic review in relation to the Research Questions above.

Figure 1. Pathways and direction of associations underpinning Research Questions 1-5. (Yellow=Research Question 1, blue=Research Question 2, red=Research Questions 3-5)



Methods

Search strategy

We anticipated a large body of literature relating to RQ 1-4 (quantitative data), so we applied a sequential series of literature search strategies. While we expected some overlap in results, having different search strategies ensured we would not miss studies relevant to each question.

We used the following electronic bibliographic databases: CINAHL (EBSCO), ERIC (EBSCO), EMBASE (OVID), MEDLINE (OVID), PsycINFO (EBSCO), IBSS (Proquest), ASSIA (Proquest), Social Science Citation Index (Web of Science), and Emerging Sources Citation Index (Web of Science).

The key terms for the search strategies related to (i) the population (young people), (ii) mobile devices and related software (e.g. smartphone, social media, mobile apps, etc.), (iii) sleep outcomes (e.g. sleep duration, sleeplessness, night awakening etc.), and (iv) mental health. The Medline search string is included in Appendices A & B.

This broad electronic search strategy facilitated the identification of evidence from experimental and observational studies as well as evidence from

literature reviews. This ensured that we were able to assess the relevant and available literature showing the effect of (i) mobile device screen time/use on sleep (RQ1), (ii) causal mechanisms through which mobile device screen time/use can affect young people's sleep outcomes (RQ2), and (iii) impact on mental health (RQ3,4). RQ5 was limited to qualitative research from the searches for RQ3 and RQ4.

Key terms and subject areas within each component were combined with the Boolean operator 'OR' and all three components were combined with the Boolean operator 'AND'. We constructed and adapted search strategies for each database.

Inclusion and exclusion criteria

Only studies that met the inclusion criteria were included. All literature searches were limited to publications in English language from 2007 as this was when the first commercial smartphone was released.

Population: Young people aged 10-19 years. Studies including children <10 years or adults >19 years alongside young people were only included when results were reported for young people separately and/or if at least one third of the sample was target age group or if mean age was 10-19 years. Only Western countries classified as high-income countries (HICs) by the World Bank (<https://data.worldbank.org/income-level/high-income>) were included and all low or middle income countries (LMICs) were excluded. Literature from non-Western HICs (e.g. Japan) was collected, but not included in data extraction and synthesis as the focus for this report was restricted to countries that were culturally more similar to Scotland. Studies from the general population and findings from subsets of that sample with specific medical conditions (autism, ADHD, etc.) were included, but clinical populations, i.e. samples based on having a specific condition/disorder/disease, were excluded.

Exposures: Engagement with digital/electronic mobile devices (e.g. smartphones, tablets, laptops) and software accessible through mobile devices (e.g. social media, games, websites, messaging applications), including studies which assessed the effectiveness of mobile applications or websites designed to improve sleep or mental health outcomes. Studies which referred to screen time in general without specifying the device and/or specific use (e.g. an app) were not considered for inclusion. This was to ensure that

we captured evidence on contemporary screen technology rather than older screen technology such as televisions.

Outcomes: 1) Sleep - objectively assessed or subjectively reported indicators of sleep health, and diagnosed sleep disorders, 2) Mental health and wellbeing - indicators of absence or presence of emotional, psychological, and social well-being assessed using validated psychometric questionnaires, and/or diagnosed mental disorder.

Study types: To ensure a rapid synthesis of the evidence, we applied a hierarchical approach to study selection. First, we selected reviews from 2007 to 2019 and searched them for primary experimental and longitudinal studies that met criteria for our Research Questions. We also selected primary experimental and longitudinal studies between 2017 and 2019 because the most recent reviews conducted literature searches in 2017. We did not consider cross-sectional evidence (or reviews of cross-sectional studies) for RQ1-4 because of the limitation related to identifying temporality and causal relationships between mobile device screen time/use and sleep or mental health outcomes. Cross-sectional qualitative studies were selected to answer RQ5 in the absence of literature reviews. Studies which included open questions in questionnaires, as well as interview or focus group methodologies, were eligible for answering RQ5.

Study selection

Five authors on this report screened titles, abstracts and full texts of all potentially relevant studies (AM, JP, KS, CM, JR). To allow a rapid evidence synthesis while reducing the risk of study selection bias, a randomly selected 50% of title and abstracts (AM, CM) and 20% of full-text articles were independently screened in duplicate (AM, JP, KS, CM). The decision regarding study eligibility was cross-checked and disagreements resolved through discussion or involvement of a third reviewer.

Data extraction

We developed and tested an electronic data extraction form on two included quantitative studies and one qualitative study. We extracted the study design, sample size, population characteristics (e.g. age, gender), type of exposure and outcomes, study results (direction, effect size, statistical significance, and topics on young people's views). Data extraction for all included studies was cross-checked by a second reviewer.

Quality assessment

We assessed the quality of primary quantitative studies using The Cochrane Collaboration tool for assessing risk of bias in intervention and longitudinal observational studies. Five quality domains were assessed: (i) population selection bias, (ii) performance bias (i.e. bias in assessment of the exposure), (iii) detection bias (bias in assessment of the outcome), (iv) attrition bias (bias of missing outcome data), and (v) selective reporting bias (incomplete reporting of all outcomes). Studies were judged to be of high, unclear or low risk of bias. One researcher appraised the quality of all included reviews/studies (JR) and another researcher (AM) cross-checked the quality assessment for all studies. JR's assessment of the study quality was known to AM when cross-checking.

Qualitative research studies were appraised using the National Institute for Health and Care Excellence (NICE) appraisal checklists (14). The checklist includes 14 items which are shown in Appendix Table C. Studies were rated as being of high, unclear or low quality. One researcher appraised the quality of all included reviews/studies (JR) and another researcher cross-checked the quality appraisal for all studies (CM). We resolved disagreement in quality appraisal through discussion and, if needed, sought the opinion of a third reviewer.

Data synthesis

For data synthesis we mapped each mobile device activity (including time spent using the device) identified from the literature against its findings on sleep outcomes (RQ1-2) and mental health and wellbeing outcomes (RQ3-5). This involved providing a summary of the number of studies, characteristics of studies, and findings on sleep, mental health and wellbeing outcomes grouped by type of mobile device screen activity (e.g. social media use, gaming, mobile app use). We intended to summarise the findings across the body of evidence for each Research Question as consistent, inconsistent, fragmented or incomplete, or no evidence. However, assessment of consistency/inconsistency was not possible due to the low number of included studies for each unique relationship between type of mobile device exposure and sleep outcome (see Results). Judging consistency or inconsistency based on one or two studies is not meaningful. We indicated incompleteness and where there was no evidence of an association. In addition to narratively describing the findings addressing each Research Question, we compiled a summary of findings in tables (Appendix Tables E and F), providing details of the studies included in the review.

Results

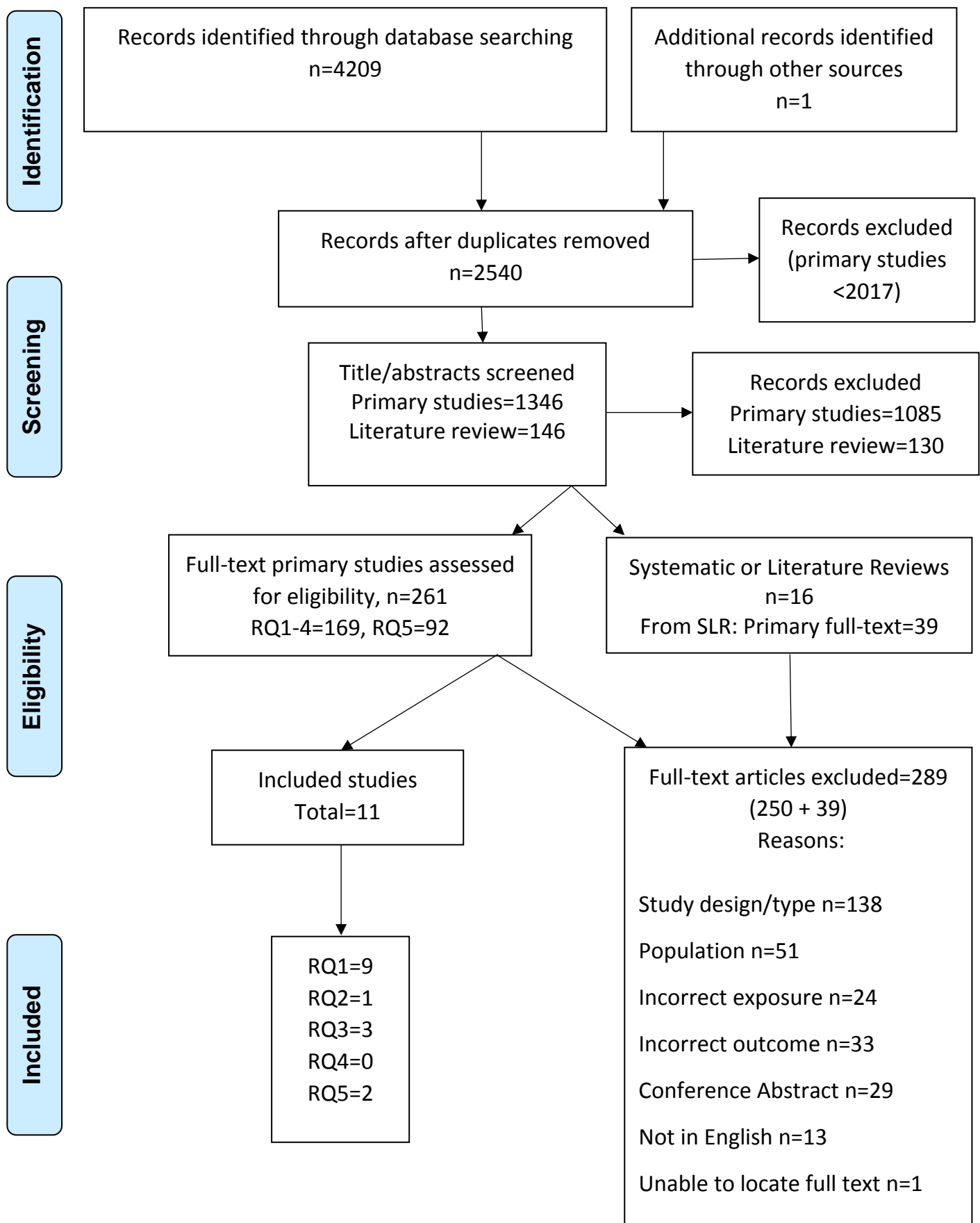
Results of the literature search

The results of the systematic literature search for all five Research Questions are summarised in Figure 2. Across all Research Questions, the search yielded 4,209 records of which we removed 1,670 duplicates. We found one additional record through other sources. Of the remaining 2,540 records, 1048 records were excluded because they were primary studies published prior to 2017. We screened the titles and abstracts of 1492 records: 146 literature reviews published 2007-2019 and 1346 primary studies published 2017-2019. Sixteen literature reviews and 261 primary studies were deemed potentially relevant and thus their full-text articles were assessed for eligibility.

Through screening of the 16 literature reviews, we identified an additional 75 potentially relevant primary studies published before 2017, which we assessed for eligibility (see Appendix Table D). Of the 75 studies, we screened 39 full-text articles, none of which met our inclusion criteria (Figure 2). Appendix Table D provides a summary of the assessed literature reviews, their aim, and the number of identified studies that appeared potentially relevant at title and abstract screening stage.

The number of included studies for each Research Question was as follows: RQ1 = 9 (15-23); RQ2 = 1 (18); RQ3 = 3 (21-23); RQ4 = 0; RQ5 = 2 (24, 25).

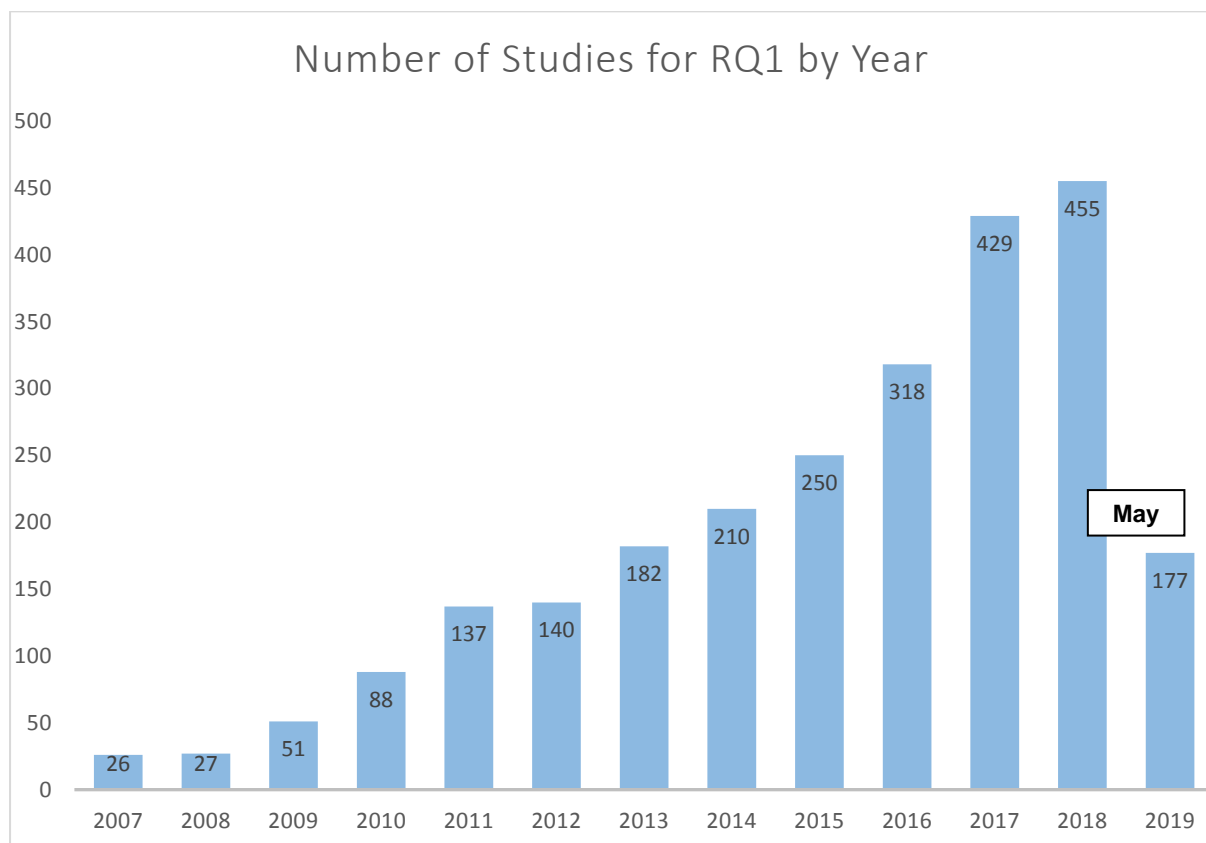
Figure 2. PRISMA flowchart for RQ1-5



Research Question 1: To what extent does adolescents' mobile device screen time impact on sleep outcomes?

Through our literature search it became evident that the number of research outputs on the links between adolescent electronic media use and sleep increased substantially over the last decade from 26 publications in 2007 to 455 publications in 2018 (Figure 3). Despite the increasing interest in this topic in the recent years, the majority of research was limited to cross-sectional studies and studies that explored the association between television screen time and sleep outcomes. Therefore, most studies were not eligible for inclusion in this review (see Figure 2). Only 9 studies met the inclusion criteria for RQ1.

Figure 3. Primary studies returned by year for RQ1



The following paragraphs describe the characteristics of the nine studies included in this literature review, their quality and the findings. The characteristics of included studies and the findings are summarised in Appendix Table E.

Description of studies

Study design, geographical location and setting

Seven studies were longitudinal observational studies (15, 17-22) and two offered an intervention to all study participants (that is, a one group before-after study design without control group (16, 23)). Two of the longitudinal observational studies used the same cohort of adolescents (21, 22). The longitudinal studies primarily tracked some form of mobile phone use (e.g. time spent on device, being cybervictimised, social media use) and collected data on sleep outcomes (e.g. duration, quality) (15, 17, 19-22). Bartel et al (16) conducted an intervention restricting adolescents' screen use before bedtime and measured school night sleep habits. Werner-Seidler et al (23) assessed the feasibility and acceptability of a smartphone application (app) designed to improve sleep and mental health outcomes in young people.

Studies were conducted in the USA (15, 17), Australia (16, 21-23), New Zealand (18), Canada (19), and Switzerland (20).

Most studies collected data through self-report questionnaires, surveys, or self-report time logs (15, 16, 18-22). Garrett et al (17) used self-report questionnaires and the number of tweets participants made. Werner-Seidler et al (23) gave participants an app and had them report on their experiences using it as well as conducting in-depth semi-structured interviews.

Sample size and participant characteristics

Sample sizes ranged from 50 to 26,205 participants. One study had a very large sample of 26,205 participants (19). Two studies had fewer than 100 participants (16, 23). The remaining six studies had between 500 and 2200 participants (15, 17, 18, 20-22).

Ages ranged from 10-28 years. Two studies did not report the age range and only provided the mean age of 14.4 years (21) and 14.3 years (20). Patte et al (19) reported neither the age range nor mean age of their sample (n=26,205), but stated that participants were secondary students in Canada, grades 9-12 (typically age 14-17 years). The two Vernon et al. studies (21, 22) used the same cohort of recruited students.

All studies had a majority of female participants ranging from 52-83% of the samples (15-23). Two studies did not report ethnicity (16, 23). Schweizer et al (20) reported on Swiss nationality but not race or ethnicity. The participant sample in Garrett et al (17) was predominantly Hispanic (30%), Asian (28%), and White Non-Hispanic (22%). The remaining five studies had participant samples that were White/European majority (56-71%) ethnicity (15, 18, 19, 21, 22).

Exposures to mobile device and screen time

Mobile device screen time. One study measured mobile device screen time as their exposure using self-report questionnaires (19). Questions included how much time participants spent texting, messaging, emailing, or talking on the phone. Some questionnaire items measured time spent in hours and others in units of time. Importantly, the study only used overall time spent on the mobile device (i.e. not just a smartphone) and did not examine whether the phone was used and when as detailed in the paragraph below.

Mobile phone use. Three studies measured mobile phone use (16, 20, 22). Two of these focussed on mobile phone use at bedtime or night time (16, 22). Vernon et al (22) asked students at what time of night they messaged or made calls and offered increments of time they could choose (e.g. 10-11pm). Bartel et al (16) asked students to record the time, in hours and minutes, they spent on their phones on school nights. Schweizer et al (20) measured student ownership of smartphones across a two-year span using self-report questionnaire data.

Social media use. Garrett et al (17) and Vernon et al (21) measured social media use in secondary students and college students, respectively. Garrett et al (17) tracked Twitter use over a semester by downloading all participant tweets and retweets. Using a machine learning model, they categorised the tweets by five emotions: fear, anger, love, joy, or neutral. Vernon et al (21) measured problematic social media use using a 4-item scale. Participants were asked to respond to statements such as, 'If I can't access Facebook/Myspace/Bebo, I feel moody and irritable' using a Likert-type response (i.e. completely disagree to completely agree).

Adverse digital communication. Three studies explored possible negative effects of digital communication using questionnaire data (15, 18, 19). Barber et al (15) asked participants about telepressure, i.e. participant views on negative social interaction using technology like phones. They used statements like the following: 'It's hard for me to focus on other things when I receive a message from someone' and participants responded using a Likert-type response (e.g. 1=strongly disagree; 5 = strongly agree). Jose et al (18) used two questions that were averaged, to assess cybervictimisation, or hurtful acts perpetrated through electronic text or pictures. Patte et al (19) assessed cybervictimisation through a single question about whether the participant was bullied in the last 30 days.

Smartphone application. There was only one study that used an app that sought to improve sleep outcomes (23). The app promoted good bedtime behaviours that promote good sleep quality (i.e. sleep hygiene) practices through six training lessons, a sleep tracking function, reminders to begin wind-down, and sleep tips.

Outcomes

All studies reported on some aspect of sleep. Four studies measured sleep duration (hours and minutes) (16, 19, 20, 23) or sleep adequacy (e.g. has participant had at least 7 or 8 hours in the last week?) (18). Four studies measured sleep quality using a range of questions and scales (17, 21-23), for example, 'In the previous 2 weeks, how often have you felt tired or sleepy during the day'. Barber et al (15) assessed sleep hygiene using the 13-item Sleep Hygiene Index with statements like, 'I go to bed at different times from day to day' and 5-point scale measuring agreement. Werner-Seidler et al (23) had many measures for sleep outcomes besides sleep duration and sleep quality, including a survey for insomnia, night awakenings, being refreshed after sleeping, sleep medication, time in bed, and sleep efficiency.

Quality of studies

Table 1 shows the rating for the quality of studies. All studies had a high risk of bias in at least one quality item. Across the studies, methodological flaws occurred in the assessment of media device screen time or use (i.e. performance bias) and assessment of sleep outcomes (i.e. detection bias) because it was self-reported in most studies. Jose et al (18) appeared to be of highest quality with selection bias and attrition bias rated as low risk of bias and high risk of bias in only one quality item. The study with the lowest quality rating was Werner-Seidler et al (23) with four quality items rated as being of high risk of bias.

Table 1. Quality assessment of included studies with sleep outcomes

Quality item	Barber 2017	Bartel 2018	Garett 2018	Jose 2018	Patte 2017	Schwiezer 2017	Vernon 2018	Vernon 2017	Werner- Seidler 2019
Selection bias	Red	Red	Red	Green	Yellow	Green	Yellow	Yellow	Red
Performance bias	Red	Yellow	Green	Yellow	Red	Red	Red	Red	Red
Detection bias	Yellow	Red	Red	Red	Red	Red	Red	Red	Red
Attrition bias	Red	Yellow	Yellow	Green	Green	Red	Green	Yellow	Red
Selective reporting bias	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

Green=low risk of bias, yellow=unclear risk of bias, Red=high risk of bias

Findings

Table 2 summarises the findings on the association between adolescent mobile screen time and sleep outcomes. The findings described below must be interpreted with caution since most are based on studies of poor quality. This means that findings are likely to be biased, in that they are not representing the true relationship between mobile screen time and sleep.

Table 2. Summary findings for RQ1

Exposures	Number of studies	Number of participants + ages	Outcomes	Summary findings
Mobile device screen time	1	N=26205 Age: 9-12 graders	Sleep duration	-/+
Mobile phone use	3	N=1755 Age: 14-16 years	Sleep duration Sleep quality Bedtime/sleep onset Sleep problem	- - -/+ -/+
Social media use	2	N=1071 Age: 14 & 18 years	Sleep quality	-
Adverse digital communication	3	N=28625 Age: 10-19 years	Sleep hygiene Sleep duration	- -
Smartphone app	1	N=28-34 Age: 12-16 years	Insomnia Sleep quality Sleep onset Night awakening Sleep duration Sleep refreshingness Time in bed after waking up Use of sleep mediation	+ + + + + + -/+ -/+

-/+ No association; + positive association; - negative association

Mobile device screen time

One study (19) assessed the relationship between time spent talking on the phone, surfing the internet, texting, messaging or emailing and meeting the recommended amount of at least 8 hours sleep/night in 9-12 graders (n=26,205). Contrary to what the authors expected, Patte et al (19) found no association between these types of screen use and sleep duration over the four-year study period (Appendix Table E).

Mobile phone use

Bedtime mobile phone use. Two studies assessed the association between bedtime mobile phone use and sleep outcomes. Bartel et al (16) tested whether instructions to stop using the mobile phone one hour before

bedtime had any effect with 63 adolescents aged 16 years on average (Appendix Table E). Adolescents stopped using mobile phones 80 minutes earlier on average after one week of taking part in the intervention. Before the intervention, they stopped using the phone at 22:19 pm. After the intervention they stopped using the phone at 20:59 pm. This was statistically significant and indicated a large effect size (Appendix Table E). Two sleep-related outcomes were also statistically significantly associated with the intervention. Participants turned off the lights 17 minutes earlier and slept 21 minutes longer compared to baseline indicating a small effect size. On the other hand, findings suggested that adolescents did not go to bed significantly earlier (4 minutes earlier) and did not fall asleep any quicker: 20.9 minutes before the intervention versus 19.9 minutes after the intervention. Vernon et al (22) found that night-time mobile phone use (i.e. sending or receiving text messages or phone calls after bedtime) and poor sleep quality underwent positive linear growth over time in 1101 adolescents aged 13.5 years on average. In other words, longer mobile phone use after bedtime was associated with lower sleep quality at 1-year and 2-year follow-up (Appendix Table E).

Smartphone ownership. Assuming that ownership of a mobile phone implies use of the mobile phone, we included a third study under the exposure mobile phone use. Schwietzer et al (20) assessed the relationship between smartphone ownership and two sleep outcomes (sleep duration and sleep problems) in 591 adolescents aged 14 years on average. Participants were classed as smartphone owners (owned a smartphone at baseline and 2-year follow-up; n=383), New-owners (acquired a smartphone over a duration of 2 years; n=153), and Non-owners (did not acquire a smartphone; n=55).

Adolescents in all three groups decreased their school day sleep time between baseline and follow-up assessment by 32 minutes (Owners), 41 minutes (New-Owners) and 37 minutes (Non-owners). Although the decrease in school day sleep time is larger for New-Owners and Non-owners, mobile phone owners continued sleeping for the shortest amount of time 2-years later (7.28 hours). In comparison, the average school day sleep time was 7.54 hours for New-owners and 8.0 hours for Non-owners. The difference in sleep time at follow-up between Owners and Non-owners was statistically significant. Smartphone owners were also statistically significantly more likely to have sleep problems at baseline than adolescents who did not own a mobile phone at baseline (i.e. Non-owners and New-owners). The proportion of adolescents reporting sleep problems at baseline was 35.2% (Owners), 19.8% (Non-owners), and 15.4% (New-owners). However, there were no statistically significant differences in the proportion of adolescents reporting sleep problems between groups at 2-year follow-up. The proportion of reported sleep problems was 33.7% (Owners), 33.6% (New-Owners), and

23.4% (Non-owners). In summary, this study suggested that the ownership of a mobile phone alone is not linked to reporting of sleep problems but phone ownership of at least 2 years appeared to be linked to shorter sleep duration.

Social media use

Two studies assessed the relationship between using social media and sleep quality. Vernon et al (21) assessed the relationship between use of Facebook, Myspace, or Bebo and sleep quality in 874 adolescents aged 14 years on average. Garrett et al (17) assessed the relationship between Twitter use and sleep quality in 1st year undergraduate students (n=197) aged 18 years on average.

Self-reported baseline scores for sleep quality on 5 point scales were 2.76 in Vernon et al (21) and 3.08 in Garrett et al (22) indicating neither poor nor good sleep quality. Both studies reported a decline in sleep quality over time. A higher degree of problematic social media use was associated with poorer sleep quality over time ((21), Appendix Table E). Late-night tweeting (2:00 am – 6:00 am) on weekdays was statistically significantly linked to poorer quality of sleep. Late-night tweeting on weekends and evening tweeting (7 pm-2 am) any day of the week were not associated with sleep quality (17). When considering the emotional states of the tweets, categorised as fearful, angry, joyful, loving, or neutral, only the association between fearful tweets and lower sleep quality reached statistical significance (Appendix Table E).

Adverse digital communication

Telepressure. Telepressure, defined as experiencing pressure to socially engage using a mobile phone, was measured by researchers using six questions that were scored based on a 5-point scale (e.g. 1=strongly disagree; 5 = strongly agree). Higher scores indicated higher levels of telepressure. The baseline average score (Appendix Table E) measuring telepressure for all 241 participants was 2.84 and at the 5-9 week follow up assessment the score was 2.78. Assessment of sleep hygiene at the 5-9 week follow up showed an average score of 2.61 on a 5-point scale with higher scores indicating poorer sleep hygiene. There was a weak statistically significant positive correlation between baseline telepressure and poor sleep hygiene at follow-up and multiple regression analysis confirmed that an increase in telepressure was associated with poorer sleep hygiene. A subgroup analysis of employed versus unemployed college students found that for employed students, increased telepressure was statistically significantly associated with poor sleep hygiene, whereas for the unemployed students there was no association between telepressure and sleep hygiene. (Appendix Table E). This may suggest that staying connected to one's social network using digital media may be more detrimental to the sleep of college students with additional employment obligations (15).

Cybervictimisation. Two studies assessed the association between cybervictimisation and sleep adequacy, defined as meeting the recommended 8 hours/night of sleep one year and two years later (18), and over a period of 4 years (19).

Jose et al (18) reported that adolescents aged 10-15 years met the sleep recommendations on 5.23 nights/week on average. After one year the average was 5.07 nights/week and after two years 4.93 nights/week. After taking sex, ethnicity and age into consideration, there was a statistically significant negative association between cybervictimisation and meeting the recommended amount of sleep of at least 8 hours/night. This means, more frequent incidences of cybervictimisation were linked to fewer nights sleeping 8 hours or more. This association lasted up to two years after experiences of cybervictimisation occurred (Appendix Table E). These findings are consistent with Patte et al (19) who assessed the likelihood of meeting the sleep recommendations after experiences of cybervictimisation in a large cohort of 26,205 adolescents in 9-12th grade. After taking sex, ethnicity, and school grade into consideration, adolescents who newly experienced cybervictimisation in the last 30 days of follow-up had a reduced likelihood of sleeping at least 8 hours/week by 18%.

Smartphone application

One study (23) assessed the preliminary effects of a smartphone app on nine different sleep outcomes: insomnia, sleep quality, sleep-onset latency, night-time awakenings, sleep refreshingness, use of sleep medication, total sleep time, time in bed, and habitual sleep efficiency (Appendix Table E). Of the 50 adolescents who initially took part in the intervention, not all provided outcome data after the intervention had finished. Complete data across outcomes ranged from 68% to 58% obtained from 29 to 34 individuals. The findings from the study presented below should be interpreted with caution due to small sample sizes and poor follow-up rates.

Findings indicated improvements in seven out of the nine sleep outcomes (Appendix Table E). From baseline to post-intervention follow-up, there was a small decrease in insomnia severity scores. However, this decrease did not result in a change of the insomnia severity category and participants remained in the 'subthreshold insomnia' category. Sleep quality improved on average with participants indicating fewer sleep difficulties after using the app. Participants using the app decreased their average time it took to fall asleep by 21 minutes (pre-intervention=72min; post-intervention=51 min). Participants woke less frequently during the night reducing the number of night-awakenings to an average of 0.87 times. Total sleep time improved by 33 minutes from 7 hours 40 minutes to 8 hours 13 minutes. This increase meant that participants met the sleep recommendations of at least 8 hours of

sleep per night after using the app. Findings of the study also suggested improvements in adolescents' perception of how refreshing their sleep was on a scale ranging from 1 (=exhausted) to 5 (=very refreshed). The average baseline score was 2.37 points and the follow-up score was 2.78 points. Participants' habitual sleep efficiency improved by 5.5% from 80.1% to 85.6%). Time in bed, which is the time between waking in the morning and getting out of bed, changed minimally to an average of one minute less. There was no change in the proportion of days sleep medication that was used before and after the intervention.

RQ 1 Summary

The nine included studies provided findings for five different types of mobile device exposure in adolescents and ten different sleep outcomes. In total, 16 unique exposure-outcome relationships were assessed across the nine included studies. It became evident that there were only one or two studies available for each exposure-outcome relationship. Findings were mixed depending on the type of exposure and sleep outcome. Table 2 provides a summary overview of the body of evidence on the different exposure-outcome relationships.

Mobile phone use (especially after bedtime) and cybervictimisation, but not overall time spent engaging in mobile phone activities, was linked to lower sleep duration (including meeting the sleep guidelines). Preliminary findings from a small, poor quality study showed that using a smartphone app that teaches about the importance of consistent sleep and wake times, and recommended bedtimes, was linked to improved sleep duration. Sleep quality was also positively influenced by using the smartphone app and negatively influenced by mobile phone use in general and social media use in particular. None of the included studies assessed the link between time spent on mobile screens and adverse digital communication and sleep quality. Experiencing pressure to socially engage using a mobile phone (i.e. telepressure) was associated with poor sleep hygiene. No other mobile device exposure was related to sleep hygiene. In terms of sleep onset, stopping phone use one hour before bedtime was not linked to earlier sleep, whereas using the smartphone app was linked to earlier sleep onset. The app intervention was also associated with improved insomnia, night-awakening, and feeling refreshed after a night of sleep. Those three sleep outcomes were not assessed in other studies included in the review. There was no evidence for an association between any of the included mobile device exposures and sleep problems, time in bed after waking up and use of sleep medication.

Our confidence in the validity of the observed associations is limited for the following three reasons: (i) small number of studies for each exposure-outcome association, (ii) all but one study (19) had a small number of participants recruited, and (iii) the quality of included studies was at unclear or high risk of bias. Therefore, the available evidence on the association between adolescents' mobile device screen time/use and sleep is incomplete.

Research Question 2: What are the potential causal mechanisms through which mobile device screen time/use affects sleep outcomes amongst adolescents?

Of the studies eligible for inclusion in this systematic review, only one study Jose et al (18) provided suitable data to explore potential causal mechanisms through which mobile device exposure influences sleep outcomes. This study was also included for answering RQ1 and the quality assessment is shown in Table 1 (the study was better quality).

Jose et al (18) investigated the mediating role of ruminative coping (i.e. repetitively thinking and obsessing about distressing thoughts, emotions, and memories) and problem solving in the longitudinal association between cybervictimisation and getting at least 8 hours of sleep per night (i.e. sleep adequacy) in 2179 adolescents aged 10-15 years from New Zealand. Study characteristics, and description of assessment of cybervictimisation and sleep adequacy are shown in Appendix Table E. Ruminative coping was established using four rumination items from an existing scale (26). Adolescents were asked to indicate their agreement with, for example, "I think I must have serious problems otherwise I wouldn't feel this way". Problem solving was assessed with three items adapted from the scale (e.g. "I try to change the situation to fix the problem").

The authors indicated the following findings with regards to ruminative coping:

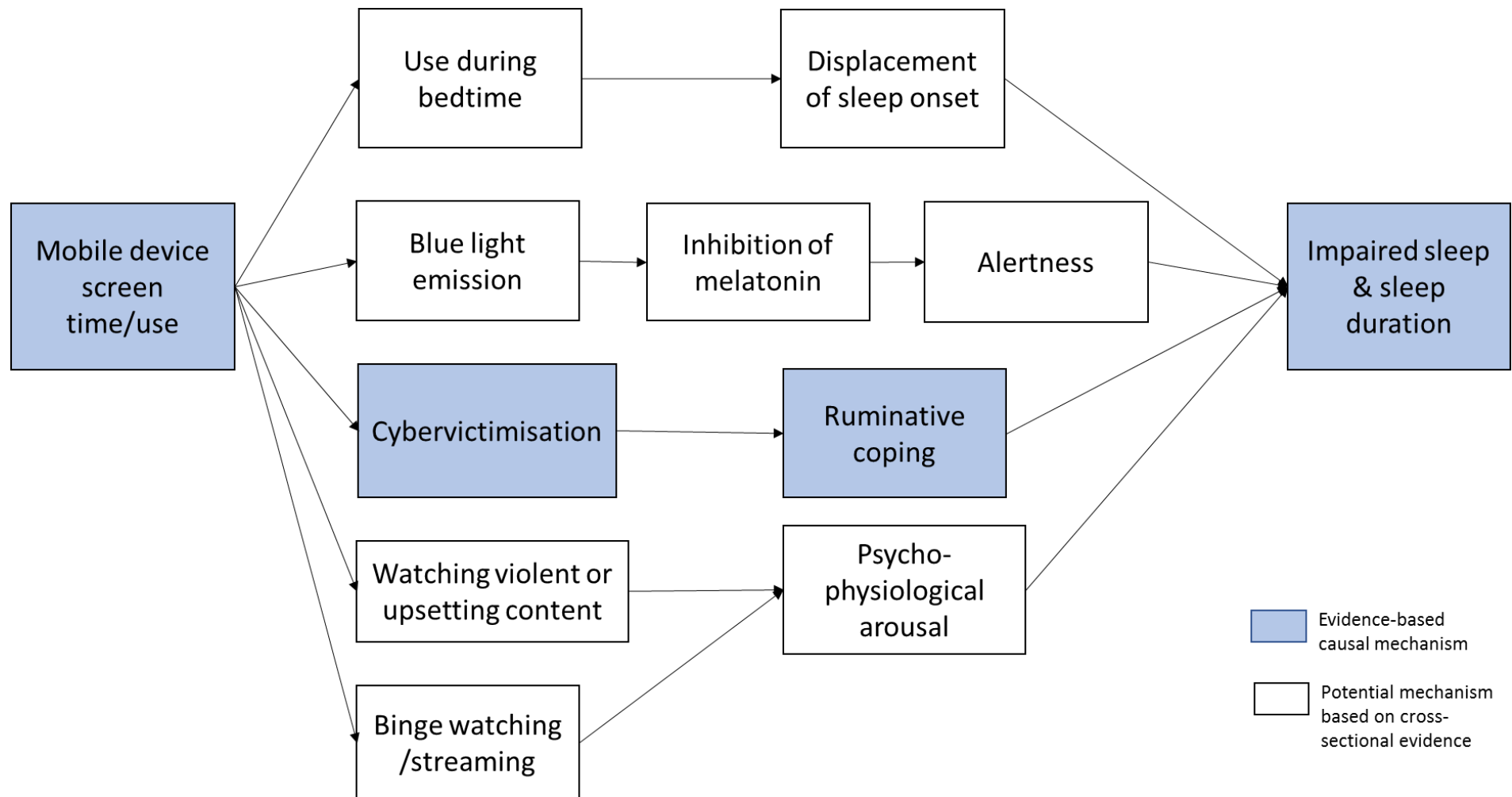
"Cybervictimisation predicted a decrease in sleep adequacy one year later through the mediating role of rumination: i.e. cybervictimisation predicted an increase in rumination and this increase, in turn, predicted a diminishment of sleep adequacy". (p. 131)

In contrast, poorer ability to solve problems was not a factor that explained the link between cybervictimisation and poor sleep adequacy.

The lack of longitudinal data limits the extent to which we can answer RQ2. However, there are a few other plausible hypotheses as to how mobile device screen time or use is linked to poor sleep outcomes among adolescents, and

a combination of factors is likely to be at play (see Figure 4). It should be noted that additionally reviewed studies (5, 27-32) are not longitudinal and while included in Figure 4 as supplementary for answering RQ2, they only give an idea of *potential* mechanisms on the pathway between screen time and sleep. Further longitudinal research is required to understand the extent to which these potential mechanisms can be evidenced.

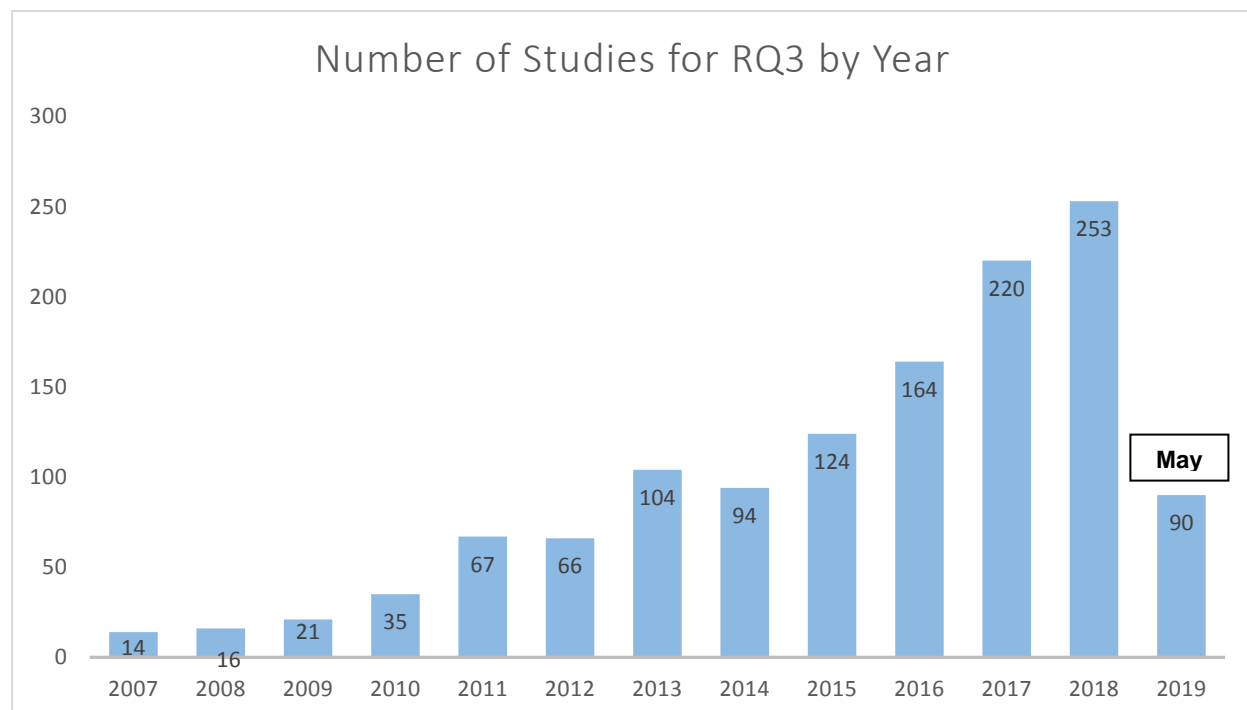
Figure 4. Potential causal pathways between mobile device screen time/use and impaired sleep



Research Question 3: What are the implications of the potential impact of mobile device screen time on sleep for adolescents' mental health and wellbeing?

As for Research Question 1, publications about the links between adolescent electronic media use, mental health and wellbeing, and sleep increased substantially over the last decade, from 14 publications in 2007 to 253 publications in 2018 (Figure 5). Much of the research included cross-sectional studies and looked at direct associations between media-sleep or media-mental health and not the indirect pathway between media-mental health via sleep. Therefore, most studies were not eligible for inclusion (see Figure 2).

Figure 5. Primary studies returned by year for RQ3



Three studies met the inclusion criteria for this Research Question (21-23). The characteristics of included studies and the findings are summarised in Appendix Table F.

Description of studies

Study design, geographical location and setting

All three studies were conducted in Australia (21-23). Two were longitudinal observational studies that used the same cohort of adolescents (21, 22), and one pilot study (i.e. the same small scale, preliminary study included in RQ1) offered an intervention to all study participants using a one group before-after study design without control group (23). One of the longitudinal studies tracked the effects of problematic social networking on adolescent psychopathology and examined sleep as a mediating variable between the two (21). The other longitudinal study examined the relationship between changes in adolescent night-time mobile phone use and sleep behaviour over time (22). The pilot study sought to test the effects and acceptability of an app that aimed to help adolescents with sleep difficulties (23).

The two longitudinal studies collected data through administering questionnaires at schools using laptops or iPads (21). For the pilot study, participants received an app and reported on their experiences using it in the home setting as well as participated in an in-depth semi-structured interview.

Sample size and participant characteristics

Sample sizes ranged from 50 to 1101 participants. The longitudinal studies had 874 participants (21) and 1101 participants (22). The pilot study had a sample size of 50 but complete outcome data for only 29 to 34 individuals in the study (23).

Participants ranged in age from 12-16 years. One study did not report the age range and only provided the mean age of 14.4 years (21). The majority of participants were female (57-66%). The Vernon et al (21, 22) studies used the same cohort of recruited students. The pilot study authors recruited adolescents with at least mild insomnia (23).

Vernon et al (21) had a sample that was 57.2% Caucasian, 7.2% Asian, and 1.6% Aboriginal or Torres Strait Islander, 23.3% other (e.g. Middle Eastern, African, Indian, or Maori), and 10% did not report ethnicity. Vernon et al (22) reported that 14 out of 27 schools that students were recruited from, were at or below the median for socioeconomic status, making 44% of the sample lower SES. The authors of the pilot study did not report ethnicity or socioeconomic status of their participants (23).

Exposures

Exposures for the three studies were related to problematic social network use (21), night-time mobile phone use (22), and an app that sought to improve sleep outcomes (23). The two longitudinal studies used self-report questionnaires to assess social network and phone use. For the pilot study, authors assessed app/intervention acceptability and non-adherence through questionnaires and interviews (23).

Outcomes

All three studies reported on mental health and wellbeing outcomes using a range of scales (e.g. the Generalised Anxiety Disorder 7-item scale or GAD-7) (23). Only one measure, coping, used a single question (22). Outcomes assessed included depressed mood, anxiety, externalising behaviour, self-esteem, and coping.

Quality of studies

Table 3 shows the quality rating of the three included studies. Each of these three studies was included in RQ1 and because they reported also on mental health and wellbeing outcomes, they received a separate quality assessment here. All three studies were of low risk of bias for assessment of mental health and wellbeing outcomes. Vernon et al (2018) was of high risk of bias due to methodological shortcomings in the assessment of night-time media use. Werner-Seidler et al (2019) was of high risk for population selection and attrition bias. Vernon et al (2017) showed limitation in reporting and did not allow assessment of the level of risk of bias for most quality items.

Table 3. Quality assessment of included studies with mental health outcomes

Quality items	Vernon et al 2018	Vernon et al 2017	Werner-Seidler et al 2019
Selection bias	Yellow	Yellow	Red
Performance bias	Red	Yellow	Green
Detection bias	Green	Green	Green
Attrition bias	Green	Yellow	Red
Selective reporting bias	Yellow	Yellow	Yellow

Green=low risk of bias, yellow=unclear risk of bias, Red=high risk of bias

Findings

Table 4 summarises the findings on the implications of the potential impact of mobile device screen time on sleep for adolescents' mental health and wellbeing. The findings described below must be interpreted with caution since most are based on studies of poor quality and may be subject to bias.

Table 4. Summary findings for RQ3

Exposures	Number of studies	Number of participants + ages	Mediator	Outcomes	Summary findings
Night-time mobile use	1	N=1101 Age: 13-16 years	Sleep quality	Depressed mood	-
				Externalising behaviour	-
				Self-esteem	-
				Coping	-
Social media use	1	N=874 Age: 14 years	Sleep quality	Depressed mood	-
				Externalising behaviour	-/+
Smartphone app	1	N=50 Age:12-16 years	App-based sleep education	Depressive Symptoms	+
				Anxiety	+

+/- no mediation effect, - negative mediating effect, + positive mediation effect

Night-time mobile phone use

Findings from a single study (21) suggested that sleep quality influenced the statistically significant associations between night-time mobile phone use and mental health outcomes (Appendix Table F). High levels of night-time mobile phone use at 13.5 years of age on average (baseline) were linked to poor sleep quality, which in turn was associated with higher levels of depressed mood, externalising behaviour, low self-esteem and poor coping abilities one year later. Poor sleep quality explained 91%, 83%, and 77% of the observed association between night-time mobile use and low self-esteem, poor coping ability, and high levels of depressed mood, respectively. The role of poor

sleep quality was less strong for the association between night-time mobile phone use and externalising behaviour. Externalising behaviours are problem behaviours directed at the external world like physical aggression or disobeying rules.

Similar findings were reported when participants showed an increased night-time use of mobile phones over a duration of two years. Change in sleep quality influenced the effect of change in night-time mobile phone use on subsequent change in all mental health outcomes. Change in sleep quality explained the association between change of night-time mobile use and depressed mood with 73%, followed by 60% for poor coping abilities, and 50% for low self-esteem.

Social media use

Using the same cohort of adolescents as for night-time mobile phone use, Vernon et al (22), assessed the mediating effect of sleep quality on the association between social media use at an average age of 14.5 years and mental health outcomes (depressive mood and externalising behaviour, like disobeying rules or physical aggression) two years later.

Findings indicated that poor sleep quality partially influenced the association between high levels of social media use and high levels of depressed mood and externalising behaviour. This means that poor sleep quality explained some of the observed link between social media use and mental health but the direct associations between social media use and the two mental health outcomes remained statistically significant.

However, when considering changes of social media use, sleep quality, depressed mood and externalising behaviour over a duration of two years, change in sleep quality fully influenced the association between changes of social media use and changes of depressed mood. Change in sleep quality partially influenced the relationship between change in social media use and change in externalising behaviour.

Smartphone application

Findings of the smartphone app intervention (a pilot study, with no comparison group) suggested an improvement in depressive symptoms immediately after using the app by -3 scores on a scale of 0-24 points (Appendix Table F).

Higher scores mean more depression. This indicated that on average, adolescents aged 12-16 years with sleep difficulties remained in the “mild symptom” category (10-14 scores) while shifting from scale point 13 at baseline to scale point 10 at follow-up. The intervention effect was small and the study was of poor quality (Appendix Table F). The effect of the app on anxiety was also small. Participants changed on average from 10 scale points indicating “moderate anxiety” (10-14 scores) at baseline to 7 scale points indicating “mild anxiety” (5-7 scores).

RQ3 Summary

The three included studies provided findings on the indirect association between three different types of mobile device exposure in adolescents and six different mental health and wellbeing outcomes. Eight unique exposure-mediator-outcome relationships (see Figure 1) were assessed across the three included studies of which each relationship was explored by no more than one study. Available evidence indicated that night-time mobile use and problematic social media use were linked to depressed mood through experiences of poor-quality sleep. A pilot study found that use of a smartphone app that teaches healthy sleep habits was potentially associated with lower depressive symptoms and reduced anxiety in the short term follow up period. Poor sleep quality also mediated the link between night-time mobile phone use and low self-esteem, poor coping skills and higher externalising behaviour. Table 4 provides a summary overview of the body of evidence on the difference exposure-outcome relationships.

Our confidence in validity of the reviewed evidence is limited for the following three reasons: (i) only one study was available for each exposure-mediator-outcome association, (ii) evidence was available for only two different cohorts of participants, and (iii) the quality of included studies was at unclear or high risk of bias. Therefore, the available evidence on the role of sleep in the association between adolescents' mobile device screen time/use and mental health is incomplete.

Research Question 4: To what extent might girls' and boys' differential mobile device screen time, and its relationship with sleep, contribute to inequalities in mental health and wellbeing by gender?

Based on the search we ran in May 2019, we found no reports that met the inclusion criteria for answering RQ4. In August 2019 a new eligible study by Viner et al (33) was published, which we did not include in our evidence synthesis because it became available after we had completed our literature search. We provide a short summary of findings below.

In a longitudinal study of 12,866 young people in England, Viner et al (33) found that using social media multiple times daily when aged 13-15 predicted lower life satisfaction, lower happiness, and higher anxiety among girls 1- to 2-years later but not among boys. Furthermore, sleeping less than 8 hours per night, not being physically active most days, and experiencing cyberbullying

play a detrimental role in the association between social media use and lower wellbeing in girls only. Therefore, the authors concluded that:

“Mental health harms related to very frequent social media use in girls might be due to a combination of exposure to cyberbullying or displacement of sleep or physical activity, whereas other mechanisms appear to be operative in boys. Interventions to promote mental health should include efforts to prevent or increase resilience to cyberbullying and ensure adequate sleep and physical activity in young people.” (33, p. 685)

Research Question 5: What existing evidence is there on adolescents' views of how mobile device screen time affects their sleep, and following on from this, their mental health and wellbeing?

Description of studies

Study design, geographical location and setting

The first study, Quante et al (24), was a mixed methods study conducted with participants living in low- and middle-income racially/ethnically diverse neighbourhoods in the USA. Focus groups were used to examine strategies to improve and promote sleep within the population.

The second study, Smahel et al (25) was conducted within the network of the EU Kids Online III project. Focus groups and interviews were used to explore children's perceptions of positive and negative experiences and consequences of using the internet and technology in general.

Sample size and participants characteristics

Quante et al (24) recruited 27 English-speaking participants aged 14-18 with a mean age of 15.7 (SD=1.4). Of these 55.6% were male; 7.4% identified as White, 11.1% as Black, 66.7% as Asian and 14.8% as 'Other'; 22.2% identified their ethnicity as Hispanic. Participants were recruited from one housing location and two youth services located within neighbourhoods within one city, described by the authors as low socioeconomic status and ethnically diverse.

Smahel et al (25) recruited 254 participants to focus groups and 114 to interview across nine countries (Belgium, Greece, Malta, Italy, Portugal, Romania, Spain, United Kingdom and the Czech Republic). Participants were recruited from three age groups (9–10 years, 11–13 years, and 14–16 years), and from a variety of schools or youth centres (e.g. public/ private, city/ suburban/ rural). Information relating to specific demographics were in the original report (34). The number of participants recruited to focus groups in each country ranged from 22 (Portugal) to 36 (Belgium) with five of the nine countries reporting an equal gender split within the sample. For the remaining four, Belgium reported 52.8% females, Malta reported 51.9% females, Portugal reported 54.5% females and Czech Republic reported 40% females. In terms of interviews, the number of participants ranged from 8 (Greece) to 20 (Belgium), with four of the nine countries reporting an equal gender split within the sample. For the remaining four, Belgium reported 55.5% females, Greece reported 62.5% females, Romania reported 54.5% females, United Kingdom reported 46.7% females and the Czech Republic reported 41.7% females.

Data collection methods

Quante et al (24) first provided participants with a survey gathering information relating to demographics, general health habits and sleep patterns. This survey also involved the Epworth Sleepiness Scale, questions from the sleep environment survey and one question from the Horne-Ostberg questionnaire which self-assesses chronotype (the propensity for the individual to sleep at a particular time during a 24-hour period). Following survey completion (approximately 10 minutes), participants were included in one of three focus groups (also described as moderator led discussions). Focus groups lasted up to one hour and used a semi-structured guide to shape discussions. Focus groups and interviews were audio- recorded, transcribed and then coded using a combination of inductive and deductive approaches.

For Smahel et al (25) limited details regarding data collection were included in the paper, instead authors referred to the larger report (34). A common topic guide was used across the nine countries. Focus groups and interviews were then transcribed in the national language, the first stage of coding involved coding condensed descriptions of material in English, next researchers translated relevant paragraphs to determine the 5-10 most interesting passages. These were then coded and analysed. The included study focused only on codes specifically linked to 'health', type of problematic situation and those that related to health issues associated with new media use.

Quality of studies

Both studies were of fairly high quality with most of the criteria checklist fulfilled (see Appendix Table C). The studies were considered poor quality in terms of richness of data, however this may be a by-product of journal word count restrictions. Table 5 provides an overview of the quality rating by criteria of NICE guideline checklist.

Table 5. Quality assessment of studies of adolescent views

Quality appraisal items	Quante et al (2019)	Smahel et al (2015)
Appropriate approach	Green	Green
Clear Aims	Green	Green
Research design	Green	Green
Data collection	Yellow	Yellow
Role of Researcher	Yellow	Yellow
Context	Yellow	Yellow
Methods	Green	Yellow
Rigorous Data Analysis	Green	Yellow
'Rich' Data	Red	Red
Reliable Analysis	Green	Green
Findings- convincing	Green	Green
Findings- relevant	Green	Green
Conclusions	Yellow	Yellow
Reporting of Ethics	Yellow	Yellow

Green=high quality, yellow=unclear, Red=low quality

Findings

Adolescents' perception of screen use and sleep

Quante et al (24) directly asked young people about their perceptions of screen use and the implications of screen use on sleep. Young people, within this study, reported being aware of specific recommendations regarding screen use prior to bedtime, although they may not always follow these guidelines. Quante et al (24) suggested that both genders reported using smartphones in bed, and recognised that it may negatively affect their sleep

'PF1: I'm addicted to my phone. Most of the time, the reason I wake up in the middle of the night is to look for my phone because I fell asleep with it.'

However, boys within the Quante et al (24) study were more likely to report trying to follow guidelines (e.g. putting electronics away one-hour pre bedtime) whilst girls suggested they specifically used their electronics as a tool to aid sleep (e.g. listening to music).

Young people involved in the Smahel et al (25) study tended to report that sleep issues were connected to the content in video games rather than their use.

'And those bad dreams, I think that is the worst, because I cannot sleep. I'm tired and then I am mad because I cannot sleep, because I'm afraid that I will have those bad dreams. Therefore, I do not want to sleep, I'm afraid and then I am so tired'.

Adolescents' perception of sleep and mental health and wellbeing

Both articles explicitly discussed mental health in relation to sleep, although these discussions were limited in nature. It should also be noted that one study (25) included sleep behaviours (e.g. sleeping problems, nightmares or being unable to sleep alone because of violent games and bad movies) within the broader category of mental health issues (e.g. cognitive salience and aggressive behaviours). Despite the references to mental health, neither study seemed to ask young people directly about their perception of the relationship between sleep and mental health, rather the concept of mental health was attached, by the authors, to comments made by the young people.

Young people within Quante et al's (24) study were prompted to discuss the importance of sleep, with participants commenting on the 'energising, relaxing, stress-reducing and restorative qualities of sleep'. Authors suggested that participants could identify consequences of poor sleep, such as adverse effects on mood and patience. Young people in both studies were reported as clearly articulating the influence of mental health (e.g. anxiety, worries or fear of nightmares) on sleep e.g.

PF2: Yeah. Thinking a lot or you just can't fall asleep. Even when I clear my mind, I can't fall asleep.

PM5: It's like when you're awake but you're sleeping. PM5: When your body is like sleeping but your mind swirls.' Quante et al (2019)

"MOD: You say yes. Why do you have trouble sleeping?

PF1: I think it's because I worry about things, and I keep on thinking about it. So I can't sleep. ' Quante et al (2019)

Adolescents' perception of the three concepts mobile device screen time, sleep and mental health and wellbeing

Neither of the two studies included asked young people explicitly about the connections between screen use, sleep and mental health.

RQ5 Summary

The authors of the studies above suggest that simply being aware of the importance of sleep and sleep guidelines does not necessarily result in behaviour change. Therefore, it is important to identify key components of interventions that may result in behaviour change. Whilst young people seemed to recognise the importance of sleep, within the included studies they rarely reported on physical and mental health problems as interconnected. Where mental health issues were reported they were often seen as being related to screen use (and content) directly rather than via sleep issues. Quante et al (24) reported differences in screen exposure by gender and propose that this suggests a need for tailored interventions.

Discussion

The objective of this systematic review was to summarise the published literature on experimental and longitudinal evidence on adolescent mobile device screen time or use, sleep and mental health and wellbeing. Five Research Questions guided this systematic review which includes evidence from both quantitative and qualitative studies.

Key Findings

Only 11 studies (quantitative=9, qualitative=2) met the inclusion criteria and were therefore the primary sources for answering the five Research Questions. As per the eligibility criteria, the included studies were conducted in Western high-income countries comparable to the UK context (USA, Canada, Australia, New Zealand, European countries). Therefore, findings are more likely to be transferrable to Scotland. Overall, the methodological quality of quantitative studies was poor and some studies lacked a detailed description of methodology which made assessing the risk of bias difficult. There were limited numbers of studies that assessed the same mobile screen device exposure and sleep or mental health outcome. In other words, there were various exposures (e.g. time spent using a mobile device, social media use) and various outcomes (e.g. sleep duration, sleep quality), and only one or two studies that assessed each exposure/outcome relationship, indicating an incomplete and inadequate body of evidence. The limitations in the quality

of studies and/or incomplete evidence means that the observed associations must be interpreted with caution as there is a high risk of bias. With this in mind, the key findings were:

RQ1 (9 quantitative studies)

- Mobile phone use around bedtime and cybervictimisation, but not the overall time spent engaging in mobile phone activities per se (at any time of the day), was linked to lower sleep duration.
- Sleep quality was negatively influenced by mobile phone use in general and social media use in particular.
- Experiencing pressure to engage socially using a mobile phone was associated with poor sleep hygiene.
- Stopping phone use one hour before bedtime was not linked to earlier sleep.
- One pilot study (a small scale, preliminary study) showed that use of a smartphone app (under development) that teaches about the importance of consistent sleep and wake times, and recommended bedtimes was associated with a potential improvement in sleep duration, sleep quality and earlier sleep onset.

RQ2 (1 quantitative study)

- Experiences of cybervictimisation were indirectly associated with sleeping less than the recommended 8 hours per night. The factor linking cybervictimisation with shorter sleep was repetitively thinking and obsessing about distressing thoughts, emotions, and memories
- Other **potential** mechanisms (that have not been evidenced in longitudinal research) through which mobile device screen time or use affect sleep outcomes are sleep displacement (i.e. using the phone instead of sleeping), delaying sleep time, increased alertness through blue light exposure, psychological arousal which can result in bodily responses (e.g. faster heart beat) through binge watching and/or watching violent or upsetting content.

RQ3 (3 quantitative studies)

- Night-time mobile use and problematic social media use were linked to depressed mood through experiences of poor-quality sleep. Poor sleep quality also affected the link between night-time mobile phone use and low self-esteem, poor coping skills and higher externalising behaviour (e.g. disobeying rules, physical aggression).
- In a pilot study, the use of a smartphone app that teaches healthy sleep habits was associated with lower depressive symptoms. The app was also associated with reduced anxiety.

RQ4 (no studies identified)

- None of the included quantitative studies reported separate data for boys' and girls' mobile device screen time or use and its relationship with sleep that in turn might contribute to inequalities in mental health and wellbeing for boys and girls differently.
- In August 2019, a new eligible study was published which we did not include in our evidence synthesis because of its availability after we had completed our literature search.
- The study found that using social media multiple times daily when aged 13-15 predicted lower life satisfaction, lower happiness, and higher anxiety among girls 1- to 2-years later but not among boys.
- It also found that sleeping less than 8 hours per night, not being physically active most days, and experiencing cyberbullying play a detrimental role in the association between social media use and lower wellbeing in girls only.

RQ5 (2 qualitative studies)

- In the qualitative studies both adolescent boys and girls reported using smartphones in bed and recognised that it may negatively affect their sleep.
- Adolescents felt that sleep issues were connected to the content in video games rather than their use.

- Boys were more likely to report trying to follow guidelines (e.g. putting electronics away one-hour pre bedtime) whilst girls suggested they specifically used their mobile screen devices as a tool to aid sleep (e.g. listening to music).
- No study asked young people directly about their perception of the relationship between sleep and mental health but thinking of the importance of sleep revealed the ‘energising, relaxing, stress-reducing and restorative qualities of sleep’.
- Young people reported the influence of mental health (e.g. anxiety, worries or fear of nightmares) on sleep.
- No study asked young people explicitly about the connections between screen use, sleep and mental health and wellbeing.

Strengths and limitations of the review process

This systematic review explored the body of knowledge on the link between use of different mobile device exposures and sleep, and the role of sleep in the association between mobile device exposures and mental health and wellbeing, taking adolescents’ views and the most recent literature into consideration.

The strengths of this review were:

- (i) Comprehensive search of literature published up to May 2019 in nine electronic databases,
- (ii) Inclusion of longitudinal observational studies, experimental studies, and qualitative research studies,
- (iii) Synthesis of the evidence for sleep and mental health and wellbeing outcomes by the different types of mobiles device screen time or use.

The nature of this work (turn-around time of 4 months) has inherent limitations which were as follows. Although a systematic search of the literature was applied, bias might have been introduced through the lack of independent duplicate screening of all articles at title/abstract and full-text stage, as well as independent duplicate data extraction and quality assessment of all included studies. Given the short timeframe for producing this evidence review no grey literature search was performed and, therefore, eligible studies and valuable evidence might have been missed, in particular on adolescents’ views.

Implications for future research

There is a large body of literature on the cross-sectional association between mobile device screen time or use and sleep but the evidence regarding change over time is scarce both in amount and quality. Only two studies tested mobile device-related interventions for improving sleep outcomes but neither of these compared the intervention to a control group. This means that it is not possible to rule out that any observed change was due to other changes in adolescents' lives rather than the intervention itself. Therefore, to be able to understand the causal relationship between mobile device screen time or use and sleep outcomes, higher-quality prospective cohort studies and controlled intervention studies are needed. Furthermore, most potential mediating factors that might be at play in the causal pathway between mobile device screen time/use and sleep outcomes have been explored with cross-sectional data. However, to assess the mediating function of variables, longitudinal study designs with appropriate statistical modelling are required.

There is very little research available on the role of impaired sleep outcomes due to mobile device screen time or use and its subsequent effect on adolescent mental health and wellbeing. Verification of the observed associations in a large cohort of adolescents is warranted. Future research should also investigate the differential associations for boys and girls to inform the development of effective interventions and recommendations for mobile device screen time and use.

Finally, the voice of young people is not well represented in the literature with only two studies identified that explored links between mobile device use and sleep outcomes. It remains unknown to what extent young people perceive the negative consequences of mobile device screen time or use on sleep as a mechanism that affects their mental health and wellbeing. Future research should also explore interventions for improving mental health and wellbeing through strategies for better sleep. A co-production approach should be at the heart of future intervention development.

Given that mobile device technology has become such an integrated part of young people's lives, mobile digital technology could be part of the solutions for improved sleep outcome and subsequent mental health and wellbeing. Interventions could build on learning from Werner-Seidler et al's (23) pilot work with the Sleep Ninja app. Automatic reminders (through machine learning technology) of when it is time to stop using the smartphone (e.g. one hour before bedtime) might be another approach worth exploring.

Implications for policy and practice

Policy and practice initiatives could target all or a combination of the identified modifiable factors within the causal pathway between mobile device screen exposures and impaired sleep, but the current evidence severely limits the recommendations that can be made. Only one study (18) provided suitable data to explore potential causal mechanisms through which mobile device exposure influences sleep outcomes. It suggests:

- Young people should be protected from cybervictimisation and mandatory requirements of social media platforms to develop algorithms that block aggressive and upsetting content could be put in place. Education on the impact of cybervictimisation and how to avoid it (e.g. adequate privacy settings) could be embedded in the school curriculum.
- Ruminative coping as a consequence of cybervictimisation could potentially be targeted by initiatives that strengthen resilience in adolescents, in particular teaching young people and their parents healthy coping strategies (e.g. help seeking and sharing thoughts/emotions, mindfulness).

Other **potential** mechanisms through which mobile device screen time or use affect sleep outcomes are displacement of sleep time, increased alertness through blue light exposure, psychophysiological arousal through binge watching and/or watching violent or upsetting content, but further research is required before policy and practice recommendations for these can be made.

The current Mental Health Strategy 2017-2027 of the Scottish Government does not explicitly state an action point that relates to the exposure of mobile device screen use (12). However, the findings of this systematic review have potential to inform Scottish Government's future mental health and wellbeing improvement activities. In 2018, the Royal College of Paediatrics and Child Health published "The health impacts of screen time: a guide for clinicians and parents" which included a recommendation based on expert opinion (rather than research evidence) that "screens are avoided for an hour before the planned bedtime" (page 8; (11)). Further guidance on reducing mobile device use before bedtime and avoidance of mobile device use during bedtime requires additional research.

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Appendices

Appendix A: Ovid Medline search string for Research Questions 1-4

Ovid MEDLINE(R) without Revisions 1996 to May Week 3

#	Searches
1	Adolescent/
2	"adolesc*".ab,ti.
3	boys.ab,ti.
4	girls.ab,ti.
5	"child*".ab,ti.
6	freshman.ab,ti.
7	freshmen.ab,ti.
8	"college student*".ab,ti.
9	"generation Y".ab,ti.
10	"Millennial*".ab,ti.
11	"Schoolchild*".ab,ti.
12	"Teen*".ab,ti.
13	"Undergraduate*".ab,ti.
14	"young people* ".ab,ti.
15	"youth*".ab,ti.
16	"young person* ".ab,ti.
17	1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16
18	Internet/
19	Online Social Networking/
20	Online social networking.ab,ti.
21	Social Media/
22	"social network*".ab,ti.
23	"SNSs".ab,ti.
24	"Social networking site* ".ab,ti.
25	"website*".ab,ti.

#	Searches
26	online.ab,ti.
27	Digital media.ab,ti.
28	electronic media.ab,ti.
29	"screen use".ab,ti.
30	"screen time".ab,ti.
31	facebook.ab,ti.
32	whatsapp.ab,ti.
33	skype.ab,ti.
34	"video streaming".ab,ti.
35	Buzzfeed.ab,ti.
36	iTunes.ab,ti.
37	Instagram.ab,ti.
38	Pinterest.ab,ti.
39	Twitter.ab,ti.
40	Tumblr.ab,ti.
41	"Chatroom*".ab,ti.
42	Cyber.ab,ti.
43	Snapchat.ab,ti.
44	Youtube.ab,ti.
45	Bebo.ab,ti.
46	Myspace.ab,ti.
47	"Blog*".ab,ti.
48	Selfie.ab,ti.
49	Sexting.ab,ti.
50	"instant messaging".ab,ti.
51	Texting.ab,ti.
52	"Vlog*".ab,ti.
53	"mobile phone*".ab,ti.
54	"mobile gaming".ab,ti.
55	cell phone.ab,ti.
56	Cell Phone/
57	cellular phone.ab,ti.

#	Searches
58	"smartphone*".ab,ti.
59	"smart phone*".ab,ti.
60	"laptop*".ab,ti.
61	ipad.ab,ti.
62	"computer tablet*".ab,ti.
63	"mobile tablet* ".ab,ti.
64	scrolling.ab,ti.
65	18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50 or 51 or 52 or 53 or 54 or 55 or 56 or 57 or 58 or 59 or 60 or 61 or 62 or 63 or 64
66	Sleep/
67	Sleep Deprivation/ or Sleep Hygiene/ or Sleep Disorders, Circadian Rhythm/ or Sleep/ or "Sleep Initiation and Maintenance Disorders"/ or Sleep Wake Disorders/
68	sleeplessness.ab,ti.
69	"sleep problem* ".ab,ti.
70	"sleep duration".ab,ti.
71	sleeping.ab,ti.
72	Sleep paralysis.ab,ti.
73	insomnia.ab,ti.
74	"sleep quality".ab,ti.
75	Sleep deprivation.ab,ti.
76	"Sleep disorder*".ab,ti.
77	"Sleep onset".ab,ti.
78	"sleep latency".ab,ti.
79	Parasomnia.ab,ti.
80	"Somatic problems".ab,ti.
81	"Circadian rhythm".ab,ti.
82	"Nightmare*".ab,ti.
83	Night awakening.ab,ti.
84	Wakefulness.ab,ti.

#	Searches
85	66 or 67 or 68 or 69 or 70 or 71 or 72 or 73 or 74 or 75 or 76 or 77 or 78 or 79 or 80 or 81 or 82 or 83 or 84
86	17 and 65 and 85
87	well-being.ab,ti.
88	wellbeing.ab,ti.
89	Mental Health/
90	mental disorder.ab,ti.
91	"mental disorder*".ab,ti.
92	"mental illness*".ab,ti.
93	Depression/
94	Anxiety/ or Anxiety Disorders/
95	Sadness/
96	Emotions/
97	"mood disorder*".ab,ti.
98	Mood Disorders/
99	Loneliness/
100	Loneliness.ab,ti.
101	isolation.ab,ti.
102	isolated.ab,ti.
103	Self Concept/
104	self-esteem.ab,ti.
105	resilient.ab,ti.
106	resilience.ab,ti.
107	"social anxiety".ab,ti.
108	FOMO.ab,ti.
109	"Fear of Missing Out".ab,ti.
110	"Vulnerabl*".ab,ti.
111	Stress.ab,ti.
112	Fatigue.ab,ti.
113	Tiredness.ab,ti.
114	Fatigue/
115	Suicide/
116	suicide.ab,ti.

#	Searches
117	Suicidal ideation.ab,ti.
118	self-harm.ab,ti.
119	Self-Injurious Behavior/
120	"Quality of Life"/
121	87 or 88 or 89 or 90 or 91 or 92 or 93 or 94 or 95 or 96 or 97 or 98 or 99 or 100 or 101 or 102 or 103 or 104 or 105 or 106 or 107 or 108 or 109 or 110 or 111 or 112 or 113 or 114 or 115 or 116 or 117 or 118 or 119 or 120
122	86 and 121
123	limit 86 to yr="2007-2019"

Appendix B: Literature search - qualitative research filter (Ovid Medline)

((("semi-structured" or semistructured or unstructured or informal or "in-depth" or indepth or "face-to-face" or structured or guide) adj2 (interview* or discussion* or questionnaire*))).tw,kw

or

(focus group* or qualitative or ethnograph* or fieldwork or "field work" or "key informant").tw,kw

or

interviews as topic/ or focus groups/ or narration/ or qualitative research/

Appendix Table C: NICE guideline check list for qualitative studies

Study identification: Include author, title, reference, year of publication	
Checklist completed by:	
Key research question/aim:	
1. Is a qualitative approach appropriate? For example: Does the research question seek to understand processes or structures, or illuminate subjective experiences or meanings? Could a quantitative approach better have addressed the research question?	Ratings: Appropriate, Inappropriate Not Sure
Comments	
2. Is the study clear in what it seeks to do? For example: Is the purpose of the study discussed – aims/objectives/research question/s? Is there adequate/appropriate reference to the literature? Are underpinning values/assumptions/theory discussed?	Ratings: Clear Unclear Mixed
Comments	
3. How defensible/rigorous is the research design/methodology? For example: Is the design appropriate to the research question? Is a rationale given for using a qualitative approach? Are there clear accounts of the rationale/justification for the sampling, data collection and data analysis techniques used? Is the selection of cases/sampling strategy theoretically justified?	Ratings: Defensible Indefensible Not sure
Comments	
4. How well was the data collection carried out? For example: Are the data collection methods clearly described? Were the appropriate data collected to address the	Ratings: Appropriately Inappropriately Not sure/

research question? Was the data collection and record keeping systematic?	Inadequately reported
Comments	
5. Is the role of the researcher clearly described? For example: Has the relationship between the researcher and the participants been adequately considered? Does the paper describe how the research was explained and presented to the participants?	Ratings: Clearly Described Unclear Not Described
Comments	
6. Is the context clearly described? For example: Are the characteristics of the participants and settings clearly defined? Were observations made in a sufficient variety of circumstances? Was context bias considered?	Ratings: Clear Unclear Not Sure
Comments	
7. Were the methods reliable? For example: Was data collected by more than 1 method? Is there justification for triangulation, or for not triangulating? Do the methods investigate what they claim to?	Ratings: Reliable Unreliable Not sure/ Not reported
Comments	
8. Is the data analysis sufficiently rigorous? For example: Is the procedure explicit – i.e. is it clear how the data was analysed to arrive at the results? How systematic is the analysis, is the procedure reliable/dependable? Is it clear how the themes and concepts were derived from the data?	Ratings: Rigorous Not rigorous Not sure/not reported
Comments	

<p>9. Is the data 'rich'?</p> <p>For example: How well are the contexts of the data described? Has the diversity of perspective and content been explored? How well has the detail and depth been demonstrated? Are responses compared and contrasted across groups/sites?</p>	<p>Ratings: Rich Poor Not sure/not reported</p>
<p>Comments</p>	
<p>10. Is the analysis reliable?</p> <p>For example: Did more than 1 researcher theme and code transcripts/data? If so, how were differences resolved? Did participants feed back on the transcripts/data if possible and relevant? Were negative/discrepant results addressed or ignored?</p>	<p>Ratings: Reliable Unreliable Not sure/ Not reported</p>
<p>Comments</p>	
<p>11. Are the findings convincing?</p> <p>For example: Are the findings clearly presented? Are the findings internally coherent? Are extracts from the original data included? Are the data appropriately referenced? Is the reporting clear and coherent?</p>	<p>Ratings: Convincing Not convincing Not Sure</p>
<p>Comments</p>	
<p>12. Are the findings relevant to the aims of the study?</p>	<p>Ratings: Relevance Irrelevant Partially relevant</p>
<p>Comments</p>	

<p>13. Conclusions</p> <p>For example:</p> <p>How clear are the links between data, interpretation and conclusions?</p> <p>Are the conclusions plausible and coherent?</p> <p>Have alternative explanations been explored and discounted?</p> <p>Does this enhance understanding of the research topic?</p> <p>Are the implications of the research clearly defined?</p> <p>Is there adequate discussion of any limitations encountered?</p>	<p>Ratings:</p> <p>Adequate</p> <p>Inadequate</p> <p>Not sure</p>
<p>14. How clear and coherent is the reporting of ethics?</p> <p>For example:</p> <p>Have ethical issues been taken into consideration?</p> <p>Are they adequately discussed e.g. do they address consent and anonymity?</p> <p>Have the consequences of the research been considered i.e. raising expectations, changing behaviour?</p> <p>Was the study approved by an ethics committee?</p>	<p>Ratings:</p> <p>Appropriate</p> <p>Inappropriate</p> <p>Not sure/ nto reported</p>
<p>As far as can be ascertained from the paper, how well was the study conducted? (see guidance notes)</p>	<p>Rating:</p> <p>++</p> <p>+</p> <p>-</p>

Appendix Table D: Overview of reviewed published literature reviews

Author	Literature review aims	Number of potentially relevant primary studies (based on abstract)
Allen et al 2016 (35)	<p>Recognizing this gap in the literature, the research team developed the ABCs of SLEEPING mnemonic to capture constructs and practices that are commonly targeted by recommendations aimed at promoting healthy sleep. The mnemonic is the ABCs of SLEEPING, which stands for “ 1) age appropriate bedtimes and wake-times with consistency, 2) schedules and routines, 3) location, 4) exercise and diet, 5) no electronics in the bedroom or before bed, 6) positivity, 7) independence when falling asleep, and 8) needs of child met during the day, 9) equal great sleep”.</p> <p>This article uses the ABCs of SLEEPING mnemonic as an organizing framework for 1) outlining common paediatric sleep recommendations 2) reviewing and evaluating empirical research that speaks to these recommendations, and 3) identifying areas where further research is needed. The article focuses on children aged 1-12 as this encompasses the time period after most children can be expected to have developed the ability to sleep through the night (i.e. ~9 mo to 1 y), wherein parents play a major role in their children's sleep practices and routines. In organizing the article around the ABCs of SLEEPING mnemonic we hope to facilitate the ease with which non-sleep</p>	4

Author	Literature review aims	Number of potentially relevant primary studies (based on abstract)
	specialists will be able to readily recall and access the knowledge gained from reading this article, thus enhancing the clinical utility of the review. Ultimately, we hope the ABCs of SLEEPING mnemonic in tandem with this review will help to meet the identified need for comprehensive, accessible, time efficient, evidence-based resources to support non-sleep specialists' ability to provide guidance and recommendations to families around paediatric sleep problems.	
Belmon et al 2018 (36)	This systematic review summarizes the current evidence on potential determinants of children's sleep behaviour for the age of 4-12 years based on longitudinal studies, taking into account their methodological quality. It aims to provide an overview of determinants of children's sleep behaviour and stimulate future intervention development of healthy sleep interventions for children.	1
Costigan et al 2013 (37)	To present a broad overview of various health indicators related to screen time, the primary aim of this systematic review is therefore to investigate the association between time spent engaging in recreational screen based sedentary behaviour (specifically television viewing, computer/internet use, and/or electronic gaming) and the physical, behavioural and psychosocial health indicators in adolescent girls.	1
	Therefore, a secondary objective of our review was to identify studies	

Author	Literature review aims	Number of potentially relevant primary studies (based on abstract)
	examining adolescent girls that have specifically adjusted for physical activity participation in order to further understand this relationship.	
Elhai et al 2019 (38)	In the present paper, we examine the literature studying relations between problematic smartphone use (PSU) and anxiety symptom severity. We first present background on the health advantages and disadvantages of using a smartphone. Next, we provide caveats in distinguishing healthy smartphone use from unhealthy PSU, and we discuss how PSU is measured. Additionally, we discuss theoretical frameworks explaining how some people develop PSU, including Uses and Gratifications Theory, and Compensatory Internet Use Theory. We present our own theoretical model of how PSU is specifically related to anxiety. We discuss and review mental health constructs associated with PSU severity, based on prior literature. Next, we systematically review the research on PSU severity in relation to anxiety symptoms, given the recent growth of studies on this research question. Finally, we offer implications and recommendations for future research in this area.	0
Grist et al 2017 (39)	This review aims to provide a contemporary appraisal of the available research evidence for the efficacy and acceptability of mobile apps to support the management of mental health in adolescents. A secondary aim was to collate the feedback from mental health professionals and adolescents involved in these studies. This review	1

Author	Literature review aims	Number of potentially relevant primary studies (based on abstract)
	will focus on mobile phone apps only (as opposed to broad mHealth and eHealth interventions) and will include a wide remit of publication types.	
Hale et al 2018 (40)	In this article, we provide an overview of the current science on screens and sleep, with a focus on recommendations to reduce the potentially excessive influence of screen time on paediatric sleep. We then review how impaired sleep in paediatric populations may lead to a range of adverse behaviours, physical health problems and well-being outcomes. We begin with a summary of the two consensus statements on child and adolescent sleep needs. Then we summarize the range of screen habits among youth, focusing on screen habits at bedtime. Next, we review current literature on evidence of the effects of youth screen habits on sleep, and the mechanisms by which screen habits may impact sleep. We conclude with evidence-based strategies to improve sleep through sleep-friendly screen-behaviour recommendations and other take-home messages for families and practitioners	6
Harrer et al 2018 (41)	This systematic review aims to assess existing evidence regarding the effectiveness of Internet interventions on symptoms of common mental health disorders, well-being, and functioning outcomes among university students when compared with control groups.	2

Author	Literature review aims	Number of potentially relevant primary studies (based on abstract)
Joshi et al 2019 (42)	<p>This paper will examine these issues, with more breadth than depth, in order to:</p> <ol style="list-style-type: none"> 1) Provide a snapshot of the technologies used by youth and young adults; 2) Help clinicians differentiate between normal use, problematic overuse, or addictive online behaviour; 3) Provide a basic approach for clinicians to engage, screen, educate/advise, and assess technology issues to move toward the treatment of specific disorders; and 4) Help communities and institutions tackle challenging issues like cyberbullying, sexting, high-risk behaviours, and problematic Internet use (PIU). 	1
Konsta et al 2017 (43)	<p>Recent literature mainly focuses on the use of electronic media and school starting time, since these two factors have a strong impact on adolescent sleep and are modifiable. Aim of this paper is to review recent literature on these parameters.</p>	4
Lam 2014 (44)	<p>The aim of the study is to systematically review the current literature to elicit epidemiological evidence supporting or refuting the association between Internet gaming addiction and sleep problems, including insomnia and poor sleep quality, as well as to explore the relationship between PIU and sleep problems.</p>	0

Author	Literature review aims	Number of potentially relevant primary studies (based on abstract)
Lissak 2018 (45)	This article reviews screen time effects on sleep, the cardiovascular system, orthopedics, and vision and screen time psychoneurological and social outcomes. A case study of an ADHD diagnosed nine-year-old boy presents an example of screen time in-the-field-effects and will assist to conclude the role of screen time in the formation of the psychophysiological resilience of the young generation.	14
Mustafaoğlu et al 2018 (46)	This study reviews the literature on the clinical problems that digital technology use has on children.	2
Primack et al 2017 (47)	Despite the relative recency of this phenomenon, there has been a fair amount of initial research exploring how SM interfaces with both psychosocial development and mental health conditions among young adults. We aim in this article to broadly summarize major understandings that have been gleaned to date and to summarize important future directions for research.	1
Stiglic and Viner 2019 (48)	Our aim was to systematically examine the evidence on the effects of time spent using screens on health and well-being among CYP. Systematic reviews of reviews (RoR or umbrella reviews) are particularly suited to quickly collating the strength of evidence across a very broad area to guide policy. We therefore undertook an RoR of	1

Author	Literature review aims	Number of potentially relevant primary studies (based on abstract)
	the effects of screentime of any type on CYP health and well-being outcomes.	
Stockburger and Omar 2013 (49)	Through the synopsis of articles below, this review investigates the role of media use (including Internet addiction Internet use, mobile phones and computers) on sleep, particularly as a cause of sleep disturbances. It specifically focuses on media use and the subsequent sleep disturbance in children and adolescents.	1
Thomee 2018 (8)	The purpose of this literature review was to supplement the work of the WHO expert group by carrying out a literature review of quantitative observational studies that consider links between mobile phone use and mental health from a psychological or behavioural perspective.	36
TOTAL		75
Duplicates between literature reviews and literature search in electronic database		36

Appendix Table E: Summary of findings on the relationship between mobile device screen time/use and sleep outcomes

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
Mobile device screen time					
Patte 2018	Canada Longitudinal cohort study Follow-up: 4 years	N=26,205 Age: grade 9-12 Baseline mean age: not reported Sex: 55% female Ethnicity: 71% Caucasian, 2.5% Black	Screen time: Survey which asked participants the average time per day that they spent: “watching/streaming TV shows or movies,” “playing video/computer games,” “talking on the phone,” “surfing the internet,” “texting, messaging, emailing,” and “doing homework.”	Sleep duration: Assessed by asking how much time in hours (0–9) and minutes (0, 15, 30, 45) participants usually spend sleeping per day. Responses were classified as either “meets recommendations” (≥8 h) or “insufficient sleep” (< 8 h)	Logistic regression (adjusted for (gender, grade, race/ethnicity) Talking on the telephone: OR= 1.01 (95%CI 0.98 to 1.03) Surfing the internet: OR = 1.01 (95% CI 1.00 to 1.02) Texting, messaging, or emailing: OR= 1.00 (95%CI 0.99 to 1.01)

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
Mobile phone use					
Bartel 2018	Australia Single arm pre-post intervention design Follow-up: 2 weeks	N=98 (63 included in analysis) Age: 14-18 years Baseline mean age: 16.3 years Sex: 83% female Ethnicity: Other: Android phone users only	Pre-bed mobile phone use on school nights: Adolescents were given individualized phone stop times, 1 hour before bed for one school week. At the end of the baseline week, average bedtimes were used to calculate the time which each adolescent needed to stop their mobile phone use, for the school week only (Sunday–Thursday night). This was 1 hour prior to their average baseline weekday bedtime. Instructions were sent to individual email addresses. Participants installed free screen On/Off Logger Lite' application which	An online sleep diary used to collect sleep outcomes for two consecutive weeks; only weekday data were used. Bedtime:	Baseline: 22:17 pm (SE 0:07) Follow-up: 22:13 pm (SE 0:08) Non-significant pre-post difference, $F=0.46$, $p=0.50$ Cohen's $d = 0.06$
				Light out time: Defined as turning the light off with the intention of sleeping,	Baseline: 22:57 pm (SE 0:07) Follow-up: 22:40 pm (SE 0:08) $F=9.00$, $p=0.01$

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
			records when phone screen is turned on. App was available for Android users only.	after going to bed; obtained from the sleep diary; unit=clock time	Cohen's d = 0.30
				Sleep onset latency: Sleep diary, minutes	Baseline: 21.0 min (SE2.2) Follow-up: 19.9 min (SE 1.9) F=0.34, p=0.57 Cohen's d = 0.06
				Total sleep time: Online sleep diary programme used an algorithm to calculate total sleep time; unit=hours:min	Baseline: 7 hrs :36 mins (SE 0:07) Follow up: 7:57 (SE 0:08) F=7.98, p=0.01 Cohen's d = 0.34
				Sleep efficacy: 3-item survey: 1. If their sleep during the intervention week was either 'better than	Completed surveys by n=29. 45% improved sleep a bit 45% sleep stayed the same 7% sleep became

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
				<p>usual', 'the same', or 'worse than usual';</p> <p>2. If they thought their sleep improved due to the intervention ('improved a bit', 'stayed the same', 'got worse');</p> <p>3. If they thought the intervention was 'highly effective', 'somewhat effective', 'neither effective nor ineffective', or 'ineffective'</p>	<p>worse</p> <p>7% reported the intervention to be highly effective</p> <p>38% be somewhat effective</p> <p>48% reported it to be neither effective nor ineffective</p> <p>7% reported it to be ineffective</p>

Schwiezer 2017	Switzerland Longitudinal cohort study Follow-up: 2 years	N=591 Age: range not reported Baseline mean age: 14.3 years Sex: 50% females Nationality: 83.5% Swiss Other: SES 5% below average, 38% above average	Smartphone ownership: Assessed using an online questionnaire, YES/NO response; answers categories into: <ul style="list-style-type: none"> - Owners (ownership at baseline and follow- up; n=383) - New owners (ownership at follow- up only, n=153) - Non-owners (those not owning a smartphone at any time-point; n=55) 	Sleep duration: Participants indicated how many hours on average they slept during school days and during weekends/vacation. Minutes are given on a decimal scale.	One-way ANOVA School days: Owners 7.28h (SD 0.09) vs Non- owners 8.00h (SD 0.20) p=0.002 Owners 7.28h (SD 0.09) vs new- owners 7.54h (SD 0.09) p=0.104 New-owners 7.54h (SD 0.09) vs Non- owners 8.00h (SD 0.20) p=0.075 Weekend/vacation: Owner vs New- owner: p=0.10 Owner vs Non- Owner: p=0.94 New-owner vs non-owner: p=0.91
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Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
				<p><i>Sleep problems:</i> Assessed by a single question: “Over the last six months have you ever had sleep problems?”. There were five possible answers dichotomized as ‘at least once a week’ (at least once a week, most days) and ‘others’ (never, less than monthly, about once a month). Yes = sleep problems</p>	<p>Bivariate analysis comparing Owners vs New-owners vs Non-owners:</p> <p>Baseline sleep problems [yes]: p<0.001</p> <p>Owners: 35.2% New-Owners: 19.8% Non-Owners: 15.4%</p> <p>Follow-up sleep problems [yes]: p=0.49</p> <p>Owners: 33.7% New-owners: 33.6% Non-Owners: 23.4%</p>

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
Vernon 2018	<p>Australia</p> <p>Longitudinal cohort study</p> <p>Follow-up: 1 year and 2 years</p>	<p>N=1101</p> <p>Age: 13-16 years</p> <p>Baseline mean age: 13.5 years</p> <p>Sex: 57% female</p> <p>Ethnicity: 56.9%Caucasian, 7.1% Asian, 2% Aboriginal or Torres Strait Islander, 21.9% other</p> <p>Other: 44% from lower SES</p>	<p>Night-Time Mobile Phone Use: Students were asked if they had a mobile phone and if they answered yes they were then asked, “At what time of the night do you usually send or receive messages and/or phone calls?” 6 response options: never text or phone after lights out; immediately after lights out; 10–11 p.m.; 11 p.m.–12 a.m.; 12–1 a.m.; 1–2 a.m.; 2–6 a.m.; at any time of the night. Coded on 6-point scale (0-5) as 0 = no mobile phone, 1 = never text or phone after lights out, 2 = immediately after lights out, 3 = before midnight, 4 = after midnight, and 5 = at any time of the night</p>	<p>Sleep quality: Assessed using a scale which consisted of the mean of eight items drawn from the School Sleep Habits Survey. The sleep scale tapped perceptions about sleep quality and behavior during the previous 2 weeks, and included: “How often have you needed more than one reminder to get up in the morning.”</p> <p>Responses for all sleep items were 1 = never, 2 = once, 3 = twice, 4 = several times, and 5 = every day/night. Higher scores = lower sleep quality</p>	<p>Zero-order correlation</p> <p>1 year follow-up: $r=0.17$, $p<0.05$</p> <p>2 year follow-up: $r=0.16$, $p<0.05$</p>

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
Social media use					
Garett 2018	USA Longitudinal cohort study Follow-up: 10 weeks	N=197 Age: 17-20 years Baseline mean age: 18.1 years Sex: 60% female Ethnicity: 29% Hispanic, 27% Asian, 22% White non-Hispanic, 12% black, 10% other Other: Students had to be active Twitter users, tweeting at least three times a week	Twitter use: All tweets and retweets were downloaded and categorized into five emotion categories: fear, anger, love, joy, or neutral using machine learning model (a Naïve Bayes classifier). The classifier used a bag-of words approach. Monograms that appeared in at least three tweets, bigrams that appeared in at least six tweets, trigrams that appeared in at least three tweets were included. Time of the day and weekday were reported.	Sleep quality: Assessed using a weekly survey (items not reported). Rating on a 5-point Likert scale (response options not reported)	Regression model (adjusted for sex, ethnicity, academic major, tweets/week) Weekday: Evening tweets β = 0.189 (SE 0.097), $p < 0.05$ Late night tweets β = - 0.937 (SE 0.352), $p < 0.01$ Weekend: Evening tweets β = -0.117 (SE 0.08), $p = > 0.05$ (value not reported) Late night tweets β = -0.413 (SE 0.139), $p > 0.05$

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
					<p>(value not reported)</p> <p>Weekdays:</p> <p>Angry tweets $\beta = -0.205$ (SE 0.169), $p > 0.05$</p> <p>Fearful tweets $\beta = -0.302$ (SE 0.131), $p < 0.05$</p> <p>Loving tweets: $\beta = 0.026$ (SE 0.138), $p > 0.05$</p> <p>Joyful tweets: $\beta = 0.105$ (SE 0.128), $p > 0.05$</p> <p>Neutral tweets: $\beta = -0.135$ (SE 0.131). $p > 0.05$</p>

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
Vernon 2017	Australia Longitudinal cohort study Follow-up: 1 year and 2 years	N=874 Age: 12-18 years Baseline mean age: 14.4 years (SD not reported) Sex: 59% female Ethnicity: 57.2% were Caucasian, 7.2% Asian, and 1.6% Aboriginal or Torres Strait Islander, 23.3% other	Social media use assessed using the problematic use of social networking scale consisting of 4 items. Items measured the degree to which adolescents invest emotionally in social networking <ul style="list-style-type: none"> Item 1: "I prefer to spend time on Facebook/ Myspace/ Bebo rather than attend social activities/ events"; Item 2: "I use Facebook/Myspace/Bebo as a way of making me feel good"; Item 3: "I get into arguments with other people about the amount of time I spend on Facebook/ Myspace/Bebo." Item 4: "If I can't access Facebook/ Myspace/Bebo, I feel moody and irritable". 	Sleep quality: Items were adapted from the School Sleep Habits Survey and asked: During the during the previous 2 weeks, how often have you: "felt tired or sleepy during the day"; "had an extremely hard time falling asleep"; "had a good night's sleep (reversed)"; "felt satisfied with your sleep" (reversed). Response option were 1 (never), 2 (once), 3 (twice), 4 (several times), and 5 (every day/night). Higher scores = poorer sleep quality	Bivariate correlation: 1 year: $r=0.34$, $p<0.01$ 2 years: $r=0.26$, $p<0.01$

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
Adverse digital communication					
Barber 2017	USA Longitudinal cohort study Follow-up: 5-9 weeks	N=241 Age: 18-28 years Baseline mean age: 19.0 (SD 1.8) Sex: 58% female Ethnicity: 64.0% White/European, 15.6% Black/African-American, 10.5% Latino/Hispanic, 4.6% Asian, 4.0% Biracial/Multi-racial. Other: Introductory Psychology course at a 4-year public university	Telepressure: assessed on a 6-item scale asking to rate the extent to which participants agree (1=strongly disagree; 5 = strongly agree) with statements that describe view on social interaction using information-communication technology (e.g. phones, emails). <ul style="list-style-type: none"> Item 1: It's hard for me to focus on other things when I receive a message for someone. Item 2: I can concentrate better on the tasks once I've responded to my messages. Item 3: I can't stop thinking about a message until I've responded. Item 4: I feel a strong need to respond to others immediately. 	Sleep hygiene: Measured using the 13-item Sleep Hygiene Index. E.g. "I go to bed at different times from day to day". Response options ranged from 1 (never) to 5 (always). Higher scores = poorer sleep hygiene.	Bivariate correlation $r=0.18$, $p<0.05$ Multiple regression: $b= 0.11$ ($SE=0.04$), $p<0.05$ Unemployed: $b = 0.01$, $SE = 0.05$, $p = 0.918$ Employed: $b = 0.27$, $SE = 0.06$, $p<0.001$ No adjustment for confounders

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
			<ul style="list-style-type: none"> Item 5: I have an overwhelming feeling to respond right at that moment when I receive a request. Item 6: It's difficult for me to resist responding to a message right away. 		
Jose 2018	New Zealand Longitudinal cohort study Follow-up: 1 year & 2 years	N=2179 (baseline) Age: 10-15 years Baseline mean age: not reported Sex: 52% female Ethnicity: 59% New Zealand European, 28% Māori, and 15% other	<p>Cybervictimisation: defined as being a victim of cyber-aggression which is defined as persistent, hurtful acts perpetrated on another individual through electronic text or pictures. Assessed asking two questions:</p> <ol style="list-style-type: none"> 1. "In the last month, about how often have you received a mean text message from someone?" 2. "In the last month, how often have you been bullied by others online?" <p>The two items were averaged to produce a single score. Responses</p>	<p>Sleep adequacy: Measured using a single survey question "In the last week, on how many nights did you get at least 8 h of sleep? Responses were provided on a scale from 0 to 7 days.</p>	<p>Bivariate correlation: 1 year: $r = -0.09$, $p < 0.01$</p> <p>2 years: $r = -0.04$, $p > 0.05$ (value not reported)</p> <p>Regression model (adjusted for sex, age, ethnic group):</p> <p>1 year: $\beta = -0.05$, $p = 0.008$</p> <p>Averaged over 2 years: $\beta = -0.08$, $p = 0.011$</p>

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
			ranges from 1 ("never"), 2 ("1 to 3 times"), 3 ("4 to 6 times"), 4 ("7 or more times") to 5 ("almost daily/daily").		
Patte 2018	Canada Longitudinal cohort study Follow-up: 4 years	N= 26,205 Age: grade 9-12 Baseline mean age: not reported Sex: 55% female Ethnicity: 71% Caucasian, 2.5% Black	Cybervictimisation: assessed using a single question "In the last 30 days, in what ways were you bullied by other students?" Response option: cyber-attacks (e.g. being sent mean text messages or having rumours spread about you on the internet) Response options included: "I have not been bullied in the last 30 days:" YES/NO scale	Sleep adequacy: Assessed by asking how much time in hours (0–9) and minutes (0, 15, 30, 45) participants usually spend sleeping per day. Responses were classified as either "meets recommendations" (≥8 h) or "insufficient sleep" (< 8 h)	Logistic regression (adjusted for (gender, grade, race/ethnicity) Adjusted OR=0.82 (95%CI 0.74 to 0.91)
Smartphone application					
Werner-Seidler 2019	Australia pilot study (single arm pre-	N=50 (baseline) Age: 12 to 16 years	Sleep Ninja App aiming to teach users about the importance of consistent sleep and wake times, and	Insomnia: Insomnia Severity Index, higher scores=more severe insomnia	$\beta=-4.29$ (95%CI -5.63 to 2.95)

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
	post intervention design) Follow-up: 6 weeks	Baseline mean age: 13.71 (SD 1.35) Sex: 66% female Other: With mild insomnia; 94% born in Australia	recommended bedtimes. The structure of the Sleep Ninja app includes six training lessons, a sleep tracking function, recommended bedtimes based on sleep guidelines, reminders to start a wind-down routine each night, a series of sleep tips and general information about sleep. Training sessions were delivered through a chat-bot format where the sleep ninja essentially acts as a sleep coach. Training sessions took approximately 5–10 min to complete. Intervention duration: 6 weeks (locked sessions thereafter)		
				Sleep Quality: Pittsburgh Sleep Quality Index, higher scores=poorer quality	$\beta = -1.88$ (95%CI -2.85 to 0.90)
				Sleep onset latency [time taken to fall asleep]	$\beta = -0.37$ (95%CI -0.70 to -0.03)
				Night-time awakenings [number]	$\beta = -0.46$ (95%CI -0.81 to -0.11)
				Sleep refreshingness [scale from 1=exhausted to 5=very refreshed]	$\beta = 0.43$ (95%CI 0.19 to 0.68)
				Use of sleep medication [proportion of days]	$\beta = -0.01$ (95% CI -0.02 to 0.01)
				Total sleep time (calculated by subtracting sleep-	$\beta = 0.53$ (95%CI 0.17 to 0.90)

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval OR=odds ratio SD=standard deviation SE=standard error
				onset latency, wake after sleep onset and time between waking and getting up in the morning, from time in bed)	
				Time in bed (time between waking in the morning and getting out of bed)	$\beta = -0.01$ minute (95%CI -0.42 to 0.41)
				Habitual sleep efficiency (total sleep time/time in bed)	$\beta = 5.25$ (95%CI 1.03 to 9.47)

Appendix Table F: Summary of findings on the relationship between mobile device screen use and mental health mediated by the impact of screen use on sleep

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
Night-time mobile phone use					
Vernon 2018	Australia Longitudinal cohort study Follow-up: 1 year	N=1101 Age: 13-16 years Baseline mean age: 13.5 years Sex: 57% female Ethnicity: 56.9%Caucasian, 7.1% Asian, 2% Aboriginal or Torres Strait Islander, 21.9% other Other: 44% from lower SES	Night-Time Mobile Phone Use: Students were asked if they had a mobile phone and if they answered yes they were then asked, “At what time of the night do you usually send or receive messages and/or phone calls?” 6 response options: never text or phone after lights out; immediately after lights out; 10–11 p.m.; 11 p.m.–12 a.m.; 12–1 a.m.; 1–2 a.m.; 2–6 a.m.; at any time of the night. Coded on 6-point scale (0-5) as 0 = no mobile phone, 1 = never text or phone after lights out, 2 = immediately after lights out, 3 = before midnight, 4 = after midnight,	Depressed mood: questionnaire based on the mean of five items designed to tap emotional well-being, originally from the Michigan Study of Adolescent Life Transitions. Items included: “How often do you feel there is nothing nice you can look forward to; feel unhappy, sad,	Latent Growth Curve Mediation Models (Mediator: sleep quality; Covariate: bedtime, gender, SES) Indirect effect intercept: B=0.29 (95%CI 0.10 to 1.75) β =0.44

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
			and 5 = at any time of the night	or depressed?" Responses ranged from 1 (never) to 6 (daily). Higher scores = worse outcome	
				Externalising behaviour: Questionnaire comprising the mean of seven items, included: "In the past 6 months how often have you skipped school without parent permission?; how often have you gotten in a physical fight with another person?" The items were	Latent Growth Curve Mediation Models (Mediator: sleep quality; Covariate: bedtime, gender, SES) Indirect effect intercept: B=0.08 (95%CI 0.01 to 1.34) β =0.12

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
				measured on an 8-point scale from 1 (none) to 8 (31 or more times), Higher scores = worse outcome	
				Self-esteem: Questionnaire based on the mean for three items and included: "How often do you feel satisfied with who you are?" Items were measured on a 6-point scale from 1 (never) to 6 (daily). The items were reverse coded	Latent Growth Curve Mediation Models (Mediator: sleep quality; Covariate: bedtime, gender, SES) Indirect effect intercept: B=0.13 (95%CI 0.04 to 0.73) β =0.15

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
				with higher scores = low self-esteem.	
				Coping: Single-item question: "How often do you feel that you are capable of coping with most of your problems?" Responses ranged from 1 (never) to 6 (daily). The item was reverse coded with higher scores = poor coping ability	Latent Growth Curve Mediation Models (Mediator: sleep quality; Covariate: bedtime, gender, SES) Indirect effect intercept: B=0.16 (95%CI 0.06 to 1.07) β =0.19
Social media use					
Vernon 2017	Australia	N=874 Age: range not reported	Social media use assessed using the problematic use of social	Depressed mood:	Latent Growth Curve Mediation Models

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
	Longitudinal cohort study Follow-up: 2 years	Baseline mean age: 14.4 years (SD not reported) Sex: 59% female Ethnicity: 57.2% were Caucasian, 7.2% Asian, and 1.6% Aboriginal or Torres Strait Islander, 23.3% other	networking scale consisting of 4 items. Items measured the degree to which adolescents invest emotionally in social networking <ul style="list-style-type: none"> Item 1: "I prefer to spend time on Facebook/ Myspace/ Bebo rather than attend social activities/ events"; Item 2: "I use Facebook/Myspace/Bebo as a way of making me feel good"; Item 3: "I get into arguments with other people about the amount of time I spend on Facebook/ Myspace/Bebo." Item 4: "If I can't access Facebook/ Myspace/Bebo, I feel moody and irritable". 	See Vernon 2018	(Mediator: sleep disruptions; Covariate: gender, SES, pubertal timing) Indirect effect intercept: B = 0.181 (95%CI 0.132 to 0.244)
				Externalising behaviour: See Vernon 2018	Latent Growth Curve Mediation Models (Mediator: sleep disruptions; Covariate: gender, SES, pubertal timing) Indirect effect intercept:

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
			Possible responses ranged from 0 (no social media profile) to 1 (completely disagree) and 5 (completely agree).		B = 0.037 (95%CI 0.019 to 0.060)
Smartphone application					
Werner-Seidler 2019	Australia pilot study (single arm pre-post intervention design) Follow-up: 6 weeks	N=50 (baseline) Age: 12 to 16 years Baseline mean age: 13.71 (SD 1.35) Sex: 66% female Other: With mild insomnia; 94% born in Australia	Sleep Ninja App aiming to teach users about the importance of consistent sleep and wake times, and recommended bedtimes. The structure of the Sleep Ninja app includes six training lessons, a sleep tracking function, recommended bedtimes based on sleep guidelines, reminders to start a wind-down routine each night, a series of sleep tips and general information about sleep. Training sessions were delivered through a chat-bot format where the sleep ninja essentially acts	Depressive symptoms: Patient Health Questionnaire-Adolescent Version (PHQ-A), asked about symptoms in preceding 2 weeks. Items scored on a 4-point scale, summed together to form a total depression score ranging from 0 to 24.	Multilevel modelling, random effects $\beta = -2.60$, $p < 0.001$ Cohen's d = 0.36

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
			as a sleep coach. Training sessions took approximately 5–10 min to complete. Intervention duration: 6 weeks (locked sessions thereafter)	0–9 = minimal symptoms, 10–14 = mild symptoms, 15–19 = moderate symptoms, 20–24 = severe depression	
				Anxiety: Generalised Anxiety Disorder 7-item scale (GAD-7), items scored on a scale from 0 (not at all) to 3 (nearly every day). Total score	Multilevel modelling, random effects $\beta = -2.56$, $p < 0.001$ Cohen's $d = 0.41$

Reference	Study characteristics	Sample characteristics	Exposure/Intervention Description	Outcome description	Findings CI=confidence interval SES=socioeconomic status
				ranging from 0 to 21: 0–4 = minimal anxiety, 5–9 = mild anxiety, 10–14= moderate anxiety, 15–21 = severe anxiety	



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This document is also available from our website at www.gov.scot.

ISBN: 978-1-83960-559-8

The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

Produced for
the Scottish Government
by APS Group Scotland
PPDAS696754 (02/20)
Published by
the Scottish Government,
February 2020

Social Research series
ISSN 2045-6964
ISBN 978-1-83960-559-8

Web and Print Publication
www.gov.scot/socialresearch

PPDAS696754 (02/20)

